Chapter 3B. Affected Environment and Environmental Consequences - Hydrodynamics

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SUMMARY

Delta hydrodynamic conditions are the influences on the movement of water in Delta channels (e.g., tidal forces and inflows) and the effects of the movement of water in Delta channels (e.g., changes in channel flows and stages, export flows, and outflow). This chapter describes Delta hydrodynamic conditions; discusses the Delta model developed by Resource Management Associates (RMA), which was used to simulate hydrodynamic effects of the DW project; identifies Delta hydrodynamic variables that could be affected by operation of the DW project; and presents results of simulations using the RMA model to determine DW project effects on those variables.

Delta hydrodynamic variables considered in the initial selection process for the hydrodynamics impact assessment were local Delta channel velocities and stages, export flows, outflows, net channel flows, and inflow source contributions. Because the most important effects of changes in outflow and changes in inflow source contributions are linked with potential water quality or fishery impacts, DW project effects associated with these changes are addressed in Chapter 3C, "Water Quality", and Chapter 3F, "Fishery Resources", rather than in this chapter. DW project effects on exports are discussed in Chapter 3A, "Water Supply and Water Project Operations". This chapter discusses potential effects of DW project diversions and discharges on local channel velocities and stages and on net channel flows.

DW project operations under Alternative 1, 2, or 3 would have less-than-significant effects on local channel velocities and stages and on net channel flows. Under cumulative conditions, however, implementation of Alternative 1, 2, or 3 could contribute to a significant effect on net channel flows. This cumulative impact would be reduced to a less-than-significant level through monitoring of the effects of DW operations and control of operations to prevent unacceptable hydrodynamic effects during periods of flows that are higher than historical flows. The No-Project Alternative would not cause adverse effects on Delta hydrodynamic conditions.

INTRODUCTION

This chapter assesses the potential impacts of the DW project on Delta hydrodynamics, the movement of water through Delta channels. Effects assessed in the impact discussion of this chapter are possible changes in net Delta channel flows and local channel flows and stages resulting from implementation of the DW project. Other effects related to hydrodynamics are discussed in this chapter but are analyzed more fully in other chapters. Chapter 3A, "Water Supply and Water Project Operations", discusses issues related to effects of the DW project on the CVP and the SWP. Chapter 3C, "Water Quality", discusses changes in levels of water quality variables that may result from changes in channel flows, including possible effects of reduced outflow on salinity intrusion. Chapter 3F, "Fishery Resources", discusses possible effects on fish habitat associated with the position of the estuarine salinity gradient that could result from changes in net channel flows and reduced Delta outflow.

The DW reservoir islands may be used for water banking or for storage and discharge of water being transferred through the Delta by other entities. The frequency and magnitude of these uses is uncertain at this time, and such uses may be subject to further environmental review. The analytical tools described in this chapter could also be used to describe the effects of these uses.

The discussion of hydrodynamics in this chapter includes several terms that may not be familiar to all readers. The following are definitions of key terms as they are used in this EIR/EIS:

- **Hydrology**. General description of the movement of water in the atmosphere, on the earth surface, in the soil, and in the ground; used in this EIR/EIS to refer to rainfall and streamflow conditions.

- **Hydraulics**. Study of the practical effects and control of moving water; used to refer to the relationship between channel geometry and flow, velocity, and depth of water.

- **Stage**. Water surface elevation; the elevation above mean sea level (msl) datum.

- **Tidal hydraulics or tidal hydrodynamics**. Water movements caused by tidal forces; used to describe the movement of water caused by tidal stage variations in San Francisco Bay.

- **Tidal prism**. The volume of water that moves past a location as the result of a change in tidal stage; used in this EIR/EIS to refer to the change in volume between low tide and high tide, estimated as the upstream water surface area times the change in tidal stage.

- **Hydraulic gradient**. Difference in water surface elevation between two points; describes the water surface slope that controls the movement of water along a channel.

- **Hydraulic radius**. Channel cross-section area divided by the perimeter of the channel; used in this EIR/EIS as the effective depth of water in a channel.

- **Conveyance**. The flow capacity of a channel related to the hydraulic radius, used to describe the flow in channels.

- **Tidal flow**. Flow caused by tidal changes in stage and hydraulic gradient; describes the fluctuating flows in a channel caused by the tide.

- **Net flow**. Long-term average of flows in a channel; used to describe the magnitude and direction of flow in a channel after flows during a tidal cycle are averaged.

- **Transport**. Movement of mass from one location to another; used in this EIR/EIS to refer to the movement of salt or fish from one location to another caused by net flows.

- **Mixing**. Exchange of mass between two volumes; used in this EIR/EIS to refer to the movement of salt or fish from one location to another caused by the tidal movement of water within the Delta channels.

- **Historical Delta flows**. Measured Delta inflows and exports, estimated Delta outflow, and simulated net channel flows corresponding to the inflows and exports.

- **Tidal excursion**. The distance between the most upstream position and most downstream position of a floating object that is released from a location at mean tide and tracked over a complete tidal cycle.

- **Model calibration**. Adjustments made to a model (i.e., equations or coefficient values) to provide results that more closely follow observed data; used especially during initial model development and testing.

- **Model confirmation**. Comparative testing of model results with measured data to determine the adequacy of model simulations for describing the observed behavior of the modeled variables; used especially during model application to conditions different from those used to calibrate the model.

AFFECTED ENVIRONMENT

Sources of Information

Ongoing studies and analyses of the Bay-Delta have served as important sources of information on hydrodynamics for this EIR/EIS (see those cited in Chapter 3A, "Water Supply and Water Project Operations"). The major source of information for this chapter was simulation results from the hydrodynamic and water quality modules of the Delta model developed by RMA. These models were used to simulate the effects of the DW project alternatives on Delta channel flows and salt transport. Appendix B1, "Hydrodynamic Modeling Methods and Results for the Delta Wetlands Project", describes the RMA Delta hydrodynamic modeling results, and Appendix B2, "Salt Transport Modeling Methods and Results for the Delta Wetlands Project", describes the RMA Delta salinity modeling results, which are based on the hydrodynamic modeling results.

Table 3B-1 lists the available hydrologic information for describing historical Delta conditions. All hydrologic information (data and model results) are presented for water years (beginning in October and ending in September; for example, water year 1967 begins on October 1, 1966, and ends on September 30, 1967). Historical Delta conditions are described with a combination of measurements and estimated values. Some historical conditions are represented by measured streamflows (i.e., Sacramento River and San Joaquin River flows), and others consist of operational records (i.e., CCWD diversions). Many historical conditions must be estimated because measurements are not available. For example, DWR estimates DCC and Georgiana Slough flows, net channel depletion, QWEST flow, and Delta outflow. This chapter presents monthly average net channel flows simulated with the RMA Delta hydrodynamic model to complete the description of historical Delta conditions.

RMA Simulations

RMA performed modeling of Delta hydrodynamic and water quality conditions based on monthly average historical hydrology for the 25-year period of water years 1967-1991 to be used in preparing this EIR/EIS. This period was selected because there are historical EC data for confirmation of model results and almost all major CVP and SWP facilities were operational during this period.

The simulated monthly average results from the RMA model were summarized with a series of relationships that describe net channel flows, EC values and chloride (Cl^-) concentrations, and inflow source contributions at key locations. These relationships were incorporated into the impact assessment models developed for this EIR/EIS (the DeltaSOS model, the Delta Drainage Water Quality [DeltaDWQ] model, and the Delta Movement of Organisms Vulnerable to Entrainment [DeltaMOVE] model), as described below and shown in Figure 3-1 in Chapter 3, "Overview of Impact Analysis Approach".

The RMA model and other models used for the impact assessment of DW project effects on hydrodynamics are described below under "Overview of Models and Modeling Tasks" in the section "Impact Assessment Methodology".

RMA Simulations and DeltaSOS

As described in more detail in Chapter 3A, DeltaSOS is the monthly Delta operations model developed by JSA to simulate operations of the DW project integrated with Delta operations of the CVP and SWP. Net channel flows simulated with the RMA model have been described in the DeltaSOS assessment model as a series of algebraic "hydraulic geometry" equations that estimate channel flow splits and diversions as a function of Delta inflows, exports, and net channel depletions. DeltaSOS results include DW project diversions and discharges.

Appendix A1, "Delta Monthly Water Budgets for Operations Modeling of the Delta Wetlands Project", describes the hydrologic inputs for DeltaSOS simulations of the DW project; Appendix A2, "DeltaSOS: Delta Standards and Operations Simulation Model", describes application of the DeltaSOS model; and Appendix A3, "DeltaSOS Simulations of the Delta Wetlands Project Alternatives", presents the DeltaSOS monthly simulation results for operations of the DW project alternatives.

RMA Simulations and DeltaDWQ

DeltaDWQ is the monthly Delta water quality model developed by JSA to simulate the effects of Delta agricultural drainage on channel EC patterns and concentrations of dissolved organic carbon (DOC). RMA model results have been incorporated into the DeltaDWQ model for assessment of DW project effects on water quality constituents. Delta channel EC patterns have been described in the DeltaDWQ assessment model as a series of algebraic "negative exponential" equations that estimate EC as a function of "effective" Delta outflow. Inflow source contributions have been described in the DeltaDWQ assessment model as mass balance "mixing" equations that estimate the inflow source contributions as a function of river inflows, exports, and diversions. Effects of DW project diversions and discharges on inflow source contributions are included in the DeltaDWQ assessment model.

DeltaDWQ is described in more detail in Chapter 3C, "Water Quality". Appendix C4, "DeltaDWQ: Delta Drainage Water Quality Model", describes the application of the DeltaDWQ model for water quality impact assessment of the DW project.

RMA Simulations and DeltaMOVE

DeltaMOVE is the monthly Delta transport model developed by JSA to simulate the effects of Delta channel flows on movement of organisms vulnerable to entrainment. DeltaMOVE is a "mass balance" model that estimates net movement from both tidal mixing and net channel flows in 10 major Delta volume elements. The results of the RMA hydrodynamic modeling have been described in the DeltaMOVE assessment model to allow evaluations of the net movement of organisms vulnerable to entrainment in exports or agricultural diversions. DeltaMOVE is described in more detail in Chapter 3F, "Fishery Resources". Appendix F2, "Biological Assessment: Impacts of the Delta Wetlands Project on Fish Species", describes the application of the DeltaMOVE model for fishery impact assessment of the DW project.

Regional Delta Hydrodynamics

Delta hydrodynamics depend primarily on the physical arrangement of Delta channels, inflows, diversions and exports from the Delta, and tides. Delta hydrodynamics govern channel flows and Delta outflow dynamics related to tidal variations in stage, velocity, and flow. Delta outflow dynamics have important effects on salinity intrusion and estuarine habitat conditions.

Delta Channels

Delta channels are generally less than 30 feet deep unless dredged and vary in width from less than 100 feet to over 1 mile. Some channels are edged with aquatic and riparian vegetation, but most are bordered by steep banks of mud or riprapped levees (Kelley 1966, DeHaven and Weinrich 1988). Vegetation is generally removed from channel margins to improve flow and facilitate levee maintenance.

Delta hydrodynamic simulations depend on accurate geometry data for each of the Delta channels. Surface area is important in determining the upstream tidal flow for a given change in stage at a Delta channel location represented by a model node. Cross-sectional area is important for estimating channel flow velocity. Cross-sectional areas and lengths of channels (with corresponding friction factors) determine divisions of flow when tidal flows can move into more than one channel. Volume determines the change in stage corresponding to a tidal inflow or outflow at a channel location. Tidal flushing at a location can be estimated as the tidal flow divided by the volume. Table B1-1 in Appendix B1 summarizes important hydraulic geometry data for major Delta channel segments.

Delta Inflows

The RMA Delta model uses five separate inflows to the Delta as simulation inputs: Sacramento River, Yolo Bypass, San Joaquin River, eastside streams (including the Mokelumne, Cosumnes, and Calaveras Rivers), and rainfall in the Delta. Historical monthly average inflows for 1967-1991 were used for simulations of historical Delta hydrodynamics using the RMA model. Historical data may not represent conditions that would occur with existing reservoir and diversion facilities and under current operations criteria. Therefore, monthly average inflows for 1967-1991 simulated by DWR's operations planning model DWRSIM are used for impact assessment modeling, as described in Chapter 3A, "Water Supply and Water Project Operations". The DWRSIM simulations are projections of Delta inflows and exports that would occur under the range of hydrologic conditions represented by the 70-year hydrologic record, but with current facilities and demand for exports and under 1995 WQCP objectives.

Historical Sacramento River flow is limited to about 80,000 cfs, with higher flows diverted to the Yolo Bypass. Flows simulated by DWRSIM for low-flow periods are similar to historical values. Differences in the monthly flows between the historical and simulated patterns may be attributed to changes in upstream reservoir operations, upstream diversions, or releases made for Delta exports (changes in demands for beneficial water uses).

Upstream storage and diversions have increased considerably in the San Joaquin River Basin during the 25-year period. Increased storage has allowed greater diversions of runoff for seasonal storage and subsequent use. The San Joaquin River inflow to the Delta is now regulated to satisfy maximum salinity standards (with minimum flows) and pulse-flow requirements, as specified in the 1995 WQCP. Although upstream storage and diversions from the eastside streams have changed over the 25-year period, historical and simulated monthly values for inflow are similar.

The monthly Delta rainfall estimate is combined with estimates of Delta ET to produce model inputs for Delta channel diversions and agricultural drainage. These estimates are described in Appendix A1 and are similar to the net channel depletion values used in DWRSIM.

Delta Diversions and Exports

Delta export pumping occurs at four locations: the CVP Tracy Pumping Plant, the SWP Banks Pumping Plant, CCWD Rock Slough intake, and Vallejo and North Bay Aqueduct pumps at Barker Slough.

Historical annual exports increased to approximately 6 MAF during the late 1980s. Exports simulated by DWRSIM for the 1995 WQCP objectives averaged about

6 MAF, except in some low runoff years when this volume of water was not available.

Delta Tidal Effects

Tidal changes strongly influence Delta channel conditions twice daily by changing water surface elevation, current velocity, and flow direction. The effects of ocean tides on Delta hydrodynamic conditions are modified by freshwater inflow and diversion rates. The extent of tidal influence depends on the tidal prism volume relative to river discharge at a particular Delta location, as described below.

Tidal effects are more intense closer to Suisun Bay, but even in the central Delta, water surface elevation can vary by more than 5 feet during one tidal cycle. Tidally influenced channel velocities can range from -2 fps to more than +3 fps (with negative figures indicating upstream flood tide flow). High river flows can cause high stages and velocities in some channel segments. Diversions and export pumping can also increase channel velocities.

Tidal effects are not uniform from day to day. There is a distinct pattern of tidal variations within a lunar month. The tidal range is greatest during "spring" tides and smallest during "neap" tides. The mean tide elevation may also change slightly during the spring-neap lunar cycle. This adds a net "tidal outflow" component to daily Delta outflow estimates. However, as described below under "Average Tide at the Downstream Boundary (Benicia)", the RMA hydrodynamic model simulated a constant average tide for every tidal day throughout each month.

Delta Outflow Effects

Salinity Intrusion. Seawater intrusion in Suisun Bay is directly related to Delta outflow patterns. Salinity intrusion in the central Delta is increased when in-Delta diversions and exports, in combination with low Delta inflow, cause net flow to reverse in the lower San Joaquin River near Antioch and Jersey Point. Some salt is transported into the central Delta by the tidal flow patterns. Historical 1968-1991 and simulated Delta salinity patterns are discussed in more detail in Chapter 3C, "Water Quality", and in Appendix B2, "Salt Transport Modeling Methods and Results for the Delta Wetlands Project". The possible effects of DW project operation on salinity intrusion are assessed in Chapter 3C.

Estuarine Entrapment Zone. The estuarine "entrapment zone", or null zone, is an important aquatic habitat region associated with high levels of biological productivity. The entrapment zone is the zone of transition between gravitational circulation and riverlike net seaward flow. Gravitational circulation is the flow pattern caused by salinity (density) gradients in which mean bottom flow is landward and mean surface flow is seaward. Gravitationally induced currents are usually small fractions of tidal currents and are weakened by enhanced vertical mixing associated with increased tidal flows (Smith 1987). In general, gravitational currents are highest in the region of the steepest salinity gradient (i.e., greatest change in salinity with distance). High outflows move the salinity gradient seaward, decreasing the influence of gravitational circulation on the Delta.

The location of the entrapment zone is determined by the magnitude and duration of Delta outflow. The zone moves seaward rapidly in response to increased freshwater discharge. With decreased discharge, the zone gradually moves upstream. The hydrodynamic behavior of the estuarine entrapment zone has been described by Arthur and Ball (1980). EPA has recently proposed that the location of the upstream boundary of the entrapment zone (salinity of 2 ppt), referred to as X2, is an appropriate estuarine management variable (San Francisco Estuary Project 1993). Estuarine habitat standards for the February-June period have been included in the 1995 WQCP. The possible effects of DW project operation on estuarine habitat conditions are assessed in Chapter 3F, "Fishery Resources".

Hydrodynamics near the DW Project Islands

Hydrodynamics in channels adjacent to DW project islands (Figure 2-1 in Chapter 2, "Delta Wetlands Project Alternatives") depend largely on overall Delta hydrodynamics. The channels bordering Bacon Island and Holland Tract function primarily as transport channels moving water toward the export pumps. Net flow in these channels generally moves upstream toward the CVP and SWP pumps and the CCWD intake. Sand Mound Slough along the west side of Holland Tract is blocked by a tide gate at the Rock Slough confluence that permits flow only to the north during ebb tides, to prevent water and salt movement into Rock Slough from Sand Mound Slough.

Webb Tract is bordered by the San Joaquin River on the north and east, Fishermans Cut on the west, and False River on the southwest. Franks Tract, a flooded island area, is south of Webb Tract. Net flow near Webb Tract is usually westerly, except during periods of low Delta inflow and high export volumes, when net flow reverses and water is transported into Old River and toward the CVP and SWP pumps.

Bouldin Island is bordered by the Mokelumne River on the north and west, Little Potato Slough on the east, and Potato Slough on the south. Net flow around Bouldin Island is nearly always toward the San Joaquin River. Reverse flows, during periods of low Delta inflow and high export volumes, occur only in Potato Slough (reverse flow to the east) along the southern edge of the island.

Existing irrigation diversions and agricultural drainage discharges probably have minor effects on adjacent channel hydrodynamics. Hydrodynamic effects of these diversions and discharges are small compared with tide-induced fluctuations in water surface elevation, velocity, and channel flow.

IMPACT ASSESSMENT METHODOLOGY

Analytical Approach and Impact Variables

Overview of Models and Modeling Tasks

As indicated above under "Sources of Information", several models have been used for the impact assessment of DW project effects on water supply, hydrodynamics, water quality, and fisheries. Results from DWRSIM were used as the initial water budget for DeltaSOS simulations of the No-Project Alternative and the DW project alternatives (see Appendix A3). Results from DeltaSOS simulations were used as the inputs for various impact assessment models. The hydrodynamic and water quality modules of the RMA Delta model were used to simulate historical monthly average net channel flows and EC patterns and to estimate inflow source contributions in major Delta channels and export locations. The results from the RMA models were incorporated into the impact assessment models. This section provides an overview of the most important steps in the formulation, calibration, confirmation, and application of these models.

Table 3B-2 summarizes preliminary calibration and confirmation tasks for the RMA Delta hydrodynamic and water quality models. The source of required data for each of the models is given in the first column. The models used in each task are listed in the second column. The preliminary calibration or confirmation analysis (i.e., purpose for each task) is listed in the third column. The fourth column indicates where the results of the analysis can be found in the EIR/EIS or in supporting references.

The RMA hydrodynamic model was originally calibrated (by adjustment of hydraulic roughness coefficients) with historical tidal stage data from several locations in the Delta. The calibration was demonstrated with July 1979 data from 12 locations. The RMA Delta hydrodynamic model is described below under "RMA Hydrodynamic Model Formulation and Assumptions"; the model and tidal calibration are also described in Appendix B1. A more complete description of the model and calibration can be found in Smith and Durbin (1989).

The long-term tide pattern at the downstream boundary (near Benicia) was used to simulate tidal hydraulics (stages, flows, and velocities) in the major Delta channels. Results of these simulations are summarized in this chapter and more fully described in Appendix B1.

Historical Delta inflows and exports were used to calibrate the RMA water quality model (by adjusting tidal mixing coefficients) with daily patterns of EC at 19 Delta locations for 1972. Flows and EC data for 1976 and 1978 were used to confirm the RMA water quality model results. These results are shown in Smith and Durbin (1989).

Historical monthly average Delta inflows and exports for water years 1967-1991 were used as inputs to the RMA Delta model to simulate monthly average net channel flows in the Delta. The simulated historical net Delta channel flows are used as a reference with which to compare the simulated No-Project Alternative channel flows. The simulated channel flows are summarized in this chapter and Appendix B1. The simulated net channel flow "split" relationships were evaluated and summarized with equations that were incorporated into the DeltaSOS model (Appendix A2). The most important net channel flow-split relationships are presented in this chapter and Appendix B1.

Because Delta channel flows were not measured during the 1967-1991 period, daily EC measurements were used to provide indirect confirmation of the RMA hydrodynamic and water quality model simulations. Monthly averages of daily EC records (minimum, mean, maximum) collected by Reclamation and DWR for 1968-1991 and compiled by CCWD (Leib pers. comm.) were used to confirm the end-of-month EC patterns simulated by the RMA Delta hydrodynamic and water quality models using monthly average inflows and exports for

1967-1991. The measured and simulated EC patterns were evaluated and summarized with equations that were incorporated into the DeltaDWQ model (Appendix C4). The results of these historical monthly EC simulations are shown in Chapter 3C and Appendix B2.

Table 3B-3 shows the three major tasks for assessment of impacts of the DW project on hydrodynamics. The assessment of hydrodynamic impacts of each DW alternative was accomplished by comparison with Delta hydrodynamic conditions simulated for the No-Project Alternative under the 1995 WQCP objectives, as described in Chapter 3A.

Delta inflows and exports and DW operations (diversions and discharges for export) were simulated with the DeltaSOS model, as described in Chapter 3A and in Appendices A2 and A3. The DWRSIM-simulated water supply conditions were compared with historical reservoir inflows and Delta conditions in Appendix A1, "Delta Monthly Water Budgets for Operations Modeling of the Delta Wetlands Project".

The Delta hydrodynamic model was used to simulate channel tidal flows and velocities during maximum DW diversions and maximum DW discharge conditions. Representative inflows and exports were selected for these simulations. The results are given in Appendix B1 and summarized in this chapter.

The results of the DeltaSOS model simulations of net flows for the No-Project Alternative and each DW project alternative are presented in this chapter as the DW project hydrodynamic impact assessment. Appendix B1 provides a more detailed description of these hydrodynamic simulations. The results of the DeltaDWQ model simulations of source contributions and EC based on the simulated channel flows are presented in Chapter 3C and Appendix B2.

RMA Hydrodynamic Model Formulation and Assumptions

The RMA Delta model, developed jointly with DWR, represents the hydrodynamic responses of the Delta to tidal fluctuations and inflows. The model is a branched one-dimensional formulation representing the Delta as a network of volume elements (nodes) and channels (links). Nodes are discrete units characterized by surface area, depth, side slope, and volume as a function of water depth (stage). Nodes are interconnected by channels (links), each characterized by length, cross-sectional area, hydraulic radius (depth), and friction factor (Manning's "n" value) as a function of water depth. Water is modeled to flow from one node to another through one or more links representing the significant channels between nodes (Smith and Durbin 1989). A node represents about half the volume of the channels connecting to the node. Thus, the full channel volume is represented by the two nodes connected to the channel (link). The RMA Delta model is formulated with approximately 375 nodes and 465 connecting channels (see Figure B1-1).

The RMA Delta model combines a hydrodynamic module and a water quality module. The hydrodynamic portion of the model simulates average velocity and flow in the cross section of each channel (link) and the average stage at each volume element (node) throughout a typical tidal stage variation and with specified monthly average inflows. Tidal flows simulated with the hydrodynamic model are used to estimate net channel flows and tidal mixing between model nodes, both of which are used to simulate mixed concentrations of water quality variables at model nodes in the RMA water quality model, as described in Appendix B2.

The hydrodynamic portion of the model operates on a 1.5-minute time step and estimates stage at the nodes and velocity and flow (and direction) in the Delta channels for a repeating average tide. The model requires boundary conditions to be specified for Delta inflows, Delta exports, and the average tidal boundary conditions at the downstream end of Suisun Bay near Benicia. Delta agricultural diversions and drainage discharges are treated as sinks or sources at appropriate nodes.

Time Step of Inputs and Calculations. The RMA model can use any desired time step for inputs. The impact assessment of the DW project used monthly average flows for the 25-year period of water years 1967-1991 and DW operations specified as monthly average diversions and discharges for each of the four DW islands. Although hydrologic conditions can be specified and used in the RMA model at a daily time step, monthly simulations are considered accurate enough for impact assessment of the DW project. Conventional water supply planning models (i.e., DWRSIM and PROSIM) simulate monthly average conditions. Seasonal and year-to-year impacts can be generally described with monthly model results. Variations in DW operations resulting from daily changes in river inflows, Delta exports, or DCC gate operations for flood control or fishery management were not simulated for the hydrodynamic impact assessments. Possible effects of daily operations of the DW project are discussed in Appendix A4, "Possible Effects of Daily Delta Conditions on Delta Wetlands Project Operations and Impact Assessments".

The RMA model summarizes hydrodynamic results as average ebb tide flow, average flood tide flow, and net (positive or negative) channel flows for each set of hydrologic inputs (net flow = ebb tide flow - flood tide flow). The sign convention of the RMA model is based on the assumption that positive flow in a channel is from a lower number node to a higher number node. Most node numbers increase from upstream to downstream so that positive channel flows correspond to river flow and ebb tide flow. Flood tide flows for these channels are negative. Because the hydrologic inputs to the RMA model for the DW impact assessment were monthly averages, the model outputs are also monthly average net channel flows. The RMA model simulates tidal hydraulics for the specified 19-year average Benicia tide, but the net channel flows are monthly averages. DW project operations are simulated as constant diversions or discharges over monthly periods.

Average Tide at the Downstream Boundary (Benicia). The tidal boundary condition used in the RMA model is the 19-year average of measured tides at Benicia typically used in Delta hydrodynamic studies. Although averaging tide measurements smooths the differences between extreme tides throughout the lunar tide cycle (28 days), it is justified because the hydrologic inputs used in the impact assessment simulations are monthly averages. The hydrodynamic model repeats this average tide for each set of monthly inputs. Because the tidal cycle is 25 hours long, net channel flows are averages for the 25-hour tidal period in units of cfs.

Hydrologic Inputs. The required hydrologic inputs for the RMA Delta model consist of monthly river inflows, Delta exports, agricultural diversions and drainage flows, and simulated DW diversions and discharges for each island. The model inputs are specified in a hydrologic input file, with monthly values for water years 1967-1991 for each required input variable. Historical inflows and exports were used for the historical simulations. Values for river inflows, Delta exports, and combined DW project diversions and discharges were obtained from DeltaSOS model results for simulation of each DW alternative and the No-Project Alternative (see Appendix A3).

Simulated Delta Facilities. The simulation results produced by the RMA model depend on assumptions regarding Delta channel configurations and geometry, the DCC gate operation pattern, Delta export pumping capacities for the CVP Tracy Pumping Plant and the SWP Banks Pumping Plant, permitted pumping rate for Banks Pumping Plant, and the tidal operation pattern of the Clifton Court intake and the Suisun Marsh salinity control gate.

The hydrodynamic analysis for this EIR/EIS included the assumption that channel geometry will remain unchanged, without any of the modifications that have been proposed by DWR for north Delta or south Delta channels. Existing CVP and SWP pumping capacities, as simulated by the DeltaSOS model (described in Appendix A2), were also assumed in the RMA model to remain unchanged. The hydrodynamic analysis assumed, however, that the proposed gate at the head of Old River was in place and operational, as described in the 1995 WQCP.

The RMA model inputs specified monthly operation (open or closed) of the Delta channel control gates at the DCC, the Suisun Marsh salinity control gate, and the proposed barrier at the head of Old River. Appendix A2 describes the assumed operation of these Delta facilities. The partial temporary barriers that have been installed and operated by DWR in the south Delta were not simulated.

Simulation of Tidal Gate Operations in the Delta. Several Delta tidal gates are operating and several others are proposed. The most important Delta tidal gates currently in operation are the gate at the entrance to Clifton Court Forebay and the Suisun Marsh salinity control gate. The RMA model also simulated operating tidal gates on Tom Paine Slough in the south Delta and on Sand Mound Slough at Rock Slough. The RMA model also simulated the DCC gates and the gates at the head of Old River, but these gates were assumed to be either open or closed during an entire month and therefore were not simulated to operate as tidal gates.

Clifton Court Forebay. Inflow to Clifton Court Forebay is controlled by a gated weir that allows inflow during high tides and prevents outflow during ebb tides. The gate is represented in the RMA Delta model by a channel that approximates the head loss through the gated weir. The RMA model computes Clifton Court inflow based on channel hydraulic characteristics and the simulated head difference between Old River and Clifton Court, assuming a constant outflow to the Banks Pumping Plant. The gate is assumed to be open for several hours near high tides to approximate the current operating schedule.

Suisun Marsh Salinity Control Gate. The RMA Delta model simulates operation of the tidal gate that controls flow into Montezuma Slough. Operation of the tidal gate produces a net inflow of Sacramento River water into the Suisun Marsh channels for salinity control. Almost all flood tide flow (i.e., out of Suisun Marsh into the Sacramento River) is blocked by the gates. During ebb tide, in contrast, the gates are held open, thus producing a net ebb flow of low-salinity water from the Sacramento River into Suisun Marsh. The magnitude of the net ebb flow depends on the Sacramento River flow.

Simulated Delta Tidal Hydraulics

In RMA hydrodynamic simulations, the same average tide is used for all specified inflows and exports. Therefore, a single pattern of Delta tidal flows induced by the average tide, without any inflows or exports, can be described for all hydraulic simulations. A more complete description of simulated Delta tidal hydraulics is given in Appendix B1, "Hydrodynamic Modeling Methods and Results for the Delta Wetlands Project". Table B1-2 in Appendix B1 shows simulated tidal flows and tidal excursions for selected Delta locations.

Simulated 25-hour average flood tide flows throughout the Delta are summarized in Figure 3B-1. Arrows indicate the direction of flow during flood tide. The flow in most Delta channels will switch direction during ebb tide. Because the RMA model uses the average tidal pattern as the underlying basis for simulation of all monthly average Delta inflows and exports, net channel flows estimated by the RMA model are in addition to the average tidal flows shown on this "tidal map" of the Delta.

Tidal flows throughout the Delta provide tidal exchange mixing that governs salinity intrusion, tidal flushing flows that control water quality, and tidal currents that may influence fish movement and transport of planktonic organisms. Because the time of peak tidal flows is delayed as the tide progresses upstream, tidal flows in the south and north Delta are out of phase with the Benicia boundary condition.

Appendix B1 presents detailed descriptions and geographical representations of tidal hydraulics at important locations throughout the Delta as simulated by the RMA hydrodynamic model. A series of figures in Appendix B1 shows simulated tidal flows over the 25-hour tidal cycle at locations in Suisun Bay; along the Sacramento, San Joaquin, Old, Middle, and Mokelumne Rivers; and in the south Delta.

Simulated Historical Delta Channel Flows

The RMA Delta hydrodynamic model was used to simulate monthly average Delta channel flows for the 25-year 1967-1991 period, based on historical monthly average inflows and exports obtained from DWR's DAYFLOW database. The resulting channel flows are described here because they provide the basic flow patterns that govern possible hydrodynamic, water quality, and fishery impacts. The specified historical inflows and exports and the simulated channel flows are described in detail in Appendix B1 (see section entitled "Simulations of Monthly Average Net Delta Channel Flows Using Historical Delta Inflows and Exports").

The channel flows simulated by the RMA model and described in this section are net flows superimposed on the average tidal flows described in the previous section. These net channel flows represent Delta hydrodynamic conditions that would have been associated with historical Delta inflows and exports during 1967-1991. Much of this period was prior to the increase in Delta export demand to the levels reached in the late 1980s. The results of this historically based simulation of Delta flows provide a reference baseline for evaluating the simulated Delta hydrodynamics for the No-Project Alternative and the DW project alternatives, in the absence of historical measurements characterizing Delta channel flows.

Sacramento River Channel Flows. Sacramento River diversions into Steamboat and Sutter Sloughs and into the DCC and Georgiana Slough are determined by channel geometry, tidal hydraulics, Sacramento River inflow, and operation of the DCC gates. Delta exports, Mokelumne River or Yolo Bypass inflows, and other Delta conditions do not substantially affect these Sacramento River diversions, according to the RMA Delta model results.

Figure 3B-2 shows the historical Sacramento River inflow and the RMA-simulated diversions to Steamboat and Sutter Sloughs, the DCC, and Georgiana Slough for water years 1967-1991. The RMA model results based on historical inflows indicate that a considerable portion (20%-40%) of the Sacramento River inflow is diverted into Steamboat and Sutter Sloughs and returned to the Sacramento River channel at Rio Vista (see Figure B1-25 in Appendix B1).

The RMA model results also indicate that a considerable portion (15%-60%) of the Sacramento River inflow is diverted into the DCC and Georgiana Slough and conveyed into the central Delta. Simulated channel flows indicate that, when the DCC is open, DCC flow is greater than Georgiana Slough flow (see Figure B1-26 in Appendix B1). Closing the DCC increases the Georgiana Slough flow but reduces diversions from the Sacramento River by about half. Because the DCC is closed when Sacramento flows are greater than 25,000 cfs, the range of diversions to the DCC and Georgiana Slough is relatively constant, between approximately 4,000 cfs and 12,000 cfs.

The RMA model results indicate that a considerable portion of Sacramento River flow below Rio Vista is diverted through Threemile Slough to the San Joaquin River. The proportion of the Sacramento River flow diverted into Threemile Slough is greatest when central Delta outflow (QWEST flow) is negative (i.e., net San Joaquin River flows are reversed upstream into the central Delta). The diverted Threemile Slough flow is usually greater than the reversed San Joaquin River flow, so that the simulated flows at Antioch (which are the sum of QWEST and Threemile Slough flows) were almost always positive.

For the simulations based on historical inflows and exports, the Suisun Marsh salinity control gate was assumed to be open (i.e., not forcing fresh water into Suisun Marsh). Net channel flows simulated to be diverted through Montezuma Slough into Suisun Marsh are about 2% of Delta outflow for moderate and high Delta outflows (see Figure B1-28). At a Delta outflow of 10,000 cfs, however, Montezuma Slough net flow is simulated to be zero. When Delta outflow is less than 10,000 cfs, a small upstream net flow transports water from Suisun Marsh into the Sacramento River channel near Collinsville.

San Joaquin River Channel Flows. The San Joaquin River divides into several distributory channels through the Delta. Figure 3B-3 shows historical 1967-1991 San Joaquin River inflow at Vernalis and flow downstream of the head of Old River simulated by the RMA model. The historical simulations did not include an Old River barrier (temporary barriers have been used in some years). The RMA model simulates diversions into the head of Old River to be about 60% of San Joaquin River inflow when the inflow is above 2,000 cfs and is not directly affected by exports. Nearly all San Joaquin River inflow is diverted into Old River when the San Joaquin River inflow is less than about 2,000 cfs (see Figure B1-30). When San Joaquin River inflow is less than 2,000 cfs, a slight reverse flow in the upper San Joaquin River below the head of Old River is simulated by the RMA model when exports exceed the San Joaquin River inflow.

Water flows out of the central Delta through the lower San Joaquin River and through Franks Tract and several connecting channels (Fishermans Cut, False River, and Dutch Slough). Central Delta water consists of inflows from the San Joaquin River and eastside streams as well as Sacramento River flow diverted through the DCC and Georgiana Slough. In the RMA model simulation, False River carries about 40% of the central Delta outflow (QWEST flow), whereas Dutch Slough carries about 5% of central Delta outflow. About 55% of total central Delta outflow remains in the main channel of the lower San Joaquin River (see Figure B1-32).

Hydraulic relationships govern the magnitude of channel flows in Old and Middle Rivers regardless of the direction of flow. As simulated by the RMA model, flows in Old and Middle Rivers move downstream during periods of high San Joaquin River inflow. During periods of low San Joaquin River inflow, Old and Middle River flows are usually reversed, however, and move from the central Delta upstream toward the Delta export locations at the Banks and Tracy Pumping Plants.

Figure 3B-4A shows the hydraulic flow split simulated by the RMA model between the Old River and Middle River channels at Bacon Island for 1967-1991 historical Delta inflows and exports. The simulation location is north of the Santa Fe Cut and Woodward Canal, which transport flows between Old and Middle Rivers, and corresponds to the tidal flow measurement stations installed by USGS and DWR in 1987. The simulated channel flows indicate that Old River conveys about 60% of the total flow and Middle River conveys about 40% of the total flow in the two channels. The simulated division of flow between Old and Middle Rivers remains consistent whether the flow is downstream during high San Joaquin River inflows or upstream to supply Delta export pumping.

USGS flow data provide an opportunity to test and confirm RMA simulations of Delta channel flows in this portion of the Delta. Figure 3B-4B shows the measured relationship between Old River and Middle River flows obtained from USGS daily measurements of channel flow for 1987-1989. The USGS measurements indicate that approximately 55% of the total flow is in Middle River near Bacon Island and about 45% is in Old River. The procedures used by USGS to calibrate the flow measurement stations have not been published. The difference between the USGS estimates and the RMA-simulated division of flows between the two channels can be resolved by adjusting values for modeled channel geometry variables (and assumed friction factors) in the two channels. These adjustments (i.e., Old River from 60% to 45% of flow) were not made for the DW project impact assessments because the likely effects of these channel flow adjustments on hydrodynamic, water quality, or fishery impacts were considered relatively minor.

Criteria for Determining Impact Significance

Assessment of the Delta hydrodynamic impacts of DW project operations was accomplished by considering hydrodynamic variables in the Delta and selecting those that would likely be changed or influenced by DW operations. The selected "impact variables" were then analyzed with the RMA Delta model to determine whether significant changes from the simulated No-Project Alternative conditions would likely occur with any proposed DW project operations.

Delta hydrodynamic variables that were determined to be outside the influence of the proposed DW project operations were not selected as impact variables. This screening evaluation was based on the recognition that basic hydrologic conditions in the Sacramento and San Joaquin River Basins and tidal fluctuations from San Francisco Bay are beyond the control of any proposed DW project operation.

Possible Hydrodynamic Impact Variables

The following types of Delta hydrodynamic variables were considered in the initial selection process:

- Local channel velocities and stages that respond to changes in tidal prism volume caused by flooding or diking of tidal wetlands, changes in channel geometry, or changes in the operation of tidal gates or major siphons;
- Delta export flows that respond to changes in pumping limitations (physical or regulatory), export demands, Delta inflows, Delta water quality standards, or required minimum Delta outflows or QWEST flows;
- Delta outflows that respond to changes in required minimum outflows, Delta inflows, Delta exports, or net in-Delta diversions;
- Delta channel net flows that respond to changes in Delta inflows, diversions, and exports; modified operations of Delta facilities (DCC, Clifton Court Forebay, and Suisun Marsh salinity control gate); and modified channel conveyance capacities that might be affected by dredging, widening, clearing, cutting of new Delta channels, installation of barriers, or the presence of different hydraulic gradients (water surface slope); and
- Delta inflow source contributions of Sacramento River or San Joaquin River inflows, eastside streams, agricultural drainage, tidal mixing from the downstream Benicia boundary, or DW project discharges.

Possible types of effects of DW operations on each hydrodynamic variable are briefly described below. Selected impact variables are summarized in Table 3B-4, with the method of analysis and assessment and the Delta locations selected to represent possible hydrodynamic effects of DW operations. Several Delta hydrodynamic variables would probably not be changed by DW project operations.

Local Channel Velocities and Stages. The DW project may change Delta hydraulics in local channels adjacent to proposed DW siphons or discharge pumps. These possible effects were evaluated with RMA Delta model simulations of flow, velocity, and stage with maximum (i.e., worst-case) DW diversions and discharges and appropriate Delta inflow and export conditions. Simulations were performed for Delta channels surrounding each DW project island (Bacon Island, Webb Tract, Bouldin Island, and Holland Tract). Results are discussed later in this chapter.

The significance criteria for possible local channel hydraulic effects were exceedance of the historical flows or exceedance of a scouring velocity threshold of approximately 3 fps (Suits pers. comm.). Channel flows in the Delta are highly variable. Increases above the historical range of channel flows may, however, cause unrecognized effects. Therefore, hydraulic effects of DW project diversions or discharges are considered significant if they increase local Delta channel flows above the historical range or if they produce channel velocities of greater than 3 fps.

Delta Exports. The DW project might change Delta exports and associated channel flows toward the export pumping plants by providing an additional source of water. Possible increases in Delta exports in general have been simulated using the DeltaSOS model, as described in Chapter 3A, "Water Supply and Water Project Operations", and Appendix A3, "DeltaSOS Simulations of the Delta Wetlands Project Alternatives". RMA Delta hydrodynamic simulations were used to evaluate potential effects of DW project operations on export volumes at individual export locations (see "Delta Inflow Source Contributions" below) and associated channel flows leading toward the export pumps.

Significance criteria for these possible effects on exports and channel flows were developed based on historically permitted export capacities and the corresponding channel flows that have been associated with historical exports. The Corps' restrictions for the SWP Banks Pumping Plant allow it to increase its diversion into Clifton Court Forebay by one-third of the San Joaquin River flow when that flow is greater than 1,000 cfs at Vernalis during December 15-March 15. The physical pumping capacity at the SWP Banks Pumping Plant that can be used to export this extra water is approximately 3,620 cfs, for a total assumed SWP and CVP export capacity of 14,500 cfs (10,300 cfs at Banks and 4,200 cfs at Tracy). The extra rate of SWP export pumping, with existing Clifton Court intake facilities, was successfully demonstrated by DWR during February 1993.

Under the Corps' restrictions for the SWP Banks Pumping Plant, DW discharges for export cannot cause Delta exports and associated channel flows to increase above specified historical export pumping rates and channel flows (3-day average of 6,680 cfs). Therefore, it is assumed that proposed DW project alternative operations would not result in significant impacts on exports or associated channel flows. Possible effects of DW operations on export water quality and fisheries are described in Chapter 3C, "Water Quality", and Chapter 3F, "Fishery Resources", respectively.

Delta Outflow. The DW project may change Delta outflow by diverting water for seasonal storage on the reservoir islands during periods of excess Delta inflows, or by discharging some or all of the stored water for increased Delta outflow to potentially benefit fish and estuarine habitat conditions as directed by water purchasers. Reducing agricultural diversions onto the DW project islands may increase Delta outflow. Possible effects of DW project operations on Delta outflows were simulated with the DeltaSOS model, as described in Chapter 3A and Appendix A3.

Proposed DW diversions to reservoir island storage would generally occur only during periods of high Delta outflow; therefore, effects on Delta outflow would often be proportionately small. However, potential DW diversions are sizable (averaging 4,000 cfs during periods of diversion), and reductions in Delta outflow during periods of DW diversions were simulated in the DeltaSOS modeling.

As discussed in Chapter 3A, the 1995 WQCP specifies monthly minimum Delta outflow objectives as necessary flows for fish transport, as necessary flows to control salinity intrusion at agricultural control locations during the irrigation season or at municipal water supply intakes, or as required outflow for estuarine habitat management. Many of the salinity standards can be approximated with "equivalent" Delta outflow standards. The minimum Delta outflow allowed by the 1995 WQCP is approximately 3,400 cfs during dry and critical year types and 4,500 cfs in other year types. During the irrigation season, the 1995 WQCP requires a minimum Delta outflow of about 7,000 cfs to control salinity intrusion at Emmaton.

SWRCB terms and conditions in any water right permit granted for DW project operations would prohibit violation of Delta outflow or salinity requirements. Therefore, the modeling performed for this impact assessment did not allow these requirements to be exceeded, and DW project effects on Delta outflow were not selected as a hydrodynamic impact variable in this chapter. However, the simulated effects of DW operations on Delta outflow are reported in Appendix B1 (Table B1-11) for 1968-1991, and the secondary effects of DW project effects are assessed in other chapters. Possible effects of reduced outflow on salinity intrusion are described in Chapter 3C, "Water Quality". Possible effects of reduced Delta outflow on the position of the estuarine salinity gradient and associated fishery habitat and transport are described in Chapter 3F, "Fishery Resources".

Delta Channel Net Flow. The DW project would change flows in some Delta channels because diversions to the DW reservoir islands and discharges from the DW islands would be modifications of existing agricultural operations. Changes in diversion and discharge from No-Project Alternative conditions include:

- reduced agricultural diversions for irrigation, salt leaching, and weed control;
- increased diversion for flooding and managing wildlife and waterfowl habitat;
- diversion of excess Delta inflow for seasonal storage on the reservoir islands, including temporary storage of water being transferred from upstream reservoirs for export; and
- discharge of seasonal storage to increase Delta export and/or increase Delta outflow.

Proposed DW operations would also modify hydraulic gradients in some Delta channels. During diversion periods of several weeks, lowered stage levels at the DW intake siphons may cause flows in several central Delta channels to increase. During the discharge periods, increased stage at the DW discharge locations may cause flows in Old and Middle Rivers and their connecting canals to increase. Potential effects of DW diversions and discharges on local Delta channel flows were simulated with the RMA Delta hydrodynamic model. The DeltaSOS assessment model was used to evaluate changes in monthly average net channel flows at selected locations.

DCC and Georgiana Slough flows simulated by the RMA model depend directly on Sacramento River inflow and are not directly affected by Delta exports or DW project operations. In contrast, net central Delta outflow downstream of the Mokelumne River (i.e., QWEST flow) would be reduced by DW diversions.

Channel flows at three locations have been selected to describe possible effects of DW project operations on Delta channel net flows:

- San Joaquin River flow at Antioch is used to indicate net Delta outflow from the central Delta. Threemile Slough flow from the Sacramento River to the San Joaquin River upstream of Jersey Point also contributes to Antioch flows. San Joaquin River flow at Antioch is almost equivalent to the flow that will be measured by USGS at Jersey Point with its newly established flow-monitoring station. (Dutch Slough contributes to Antioch flow but not to Jersey Point flow.)

- Threemile Slough flow represents flow between the Sacramento River near Emmaton and the San Joaquin River near Bradford Island, upstream of Jersey Point and False River. Threemile Slough flows are influenced by Sacramento River flow and San Joaquin River flows from the central Delta (QWEST flow). Closure of the DCC increases Threemile Slough flow because Sacramento River flows are increased and QWEST flows are reduced.

- Old River flow at Bacon Island is used to indicate flow past Bacon Island and Holland Tract. Negative flows at this location (i.e., upstream) indicate that net flow is moving toward the Delta export pumps. The Old River channel carries approximately half the total net flow toward the export pumps. The remainder flows in Middle River on the east side of Bacon and Victoria Islands. Old River therefore represents flow conditions in both Old River and Middle River. USGS has operated a flow-measuring station on Old River and Middle River downstream (north) of Woodward Canal near Bacon Island.

Delta channel flows are highly variable because of hydrologic variability in tidal flows and Delta inflows and exports. Increases in channel flows above historical flows may cause unrecognized effects. Therefore, DW project effects are considered significant if they increase channel flows above historical flows.

Delta Inflow Source Contributions. The sources of water in Delta inflows affect water quality at Delta export locations and other locations in the Delta. The water source contributions are governed by the combination of hydrologic inflows and hydrodynamic flows within the Delta. The relative contributions of inflow water from the different Delta inflow sources are especially important for subsequent water quality and fishery impact analyses.

The DW project may change the relative contributions of water in the Delta from different inflow sources by diverting water that would otherwise have been transported to other locations (e.g., to the Delta export pumps and Delta outflow). During periods of DW discharges, the DW reservoir islands would supply a new source of water that might replace other inflow sources at the Delta export pumps or Delta outflow. Possible effects of DW operations on Delta inflow source contributions have been simulated with the RMA hydrodynamic Delta model and are described in this chapter. The RMA results have been summarized in the DeltaDWQ assessment model.

Effects of DW project operations on Delta inflow source contributions were not selected as a hydrodynamic impact variable because significance criteria for changes in inflow source contributions are linked with potential fishery or water quality impacts and therefore will be described in subsequent chapters. The changes in source contributions are described and evaluated in Appendix B1, "Hydrodynamic Modeling Methods and Results for the Delta Wetlands Project"; potential water quality impacts are described in Chapter 3C, "Water Quality"; and potential fishery impacts are described in Chapter 3F, "Fishery Resources".

Summary of Criteria for Impact Significance

The hydrodynamic effects of the proposed DW project alternatives were assessed based on the following criteria:

- **Hydrodynamic effects on local channel velocities and stages**. A project alternative is considered to have a significant impact on local channel hydraulics if it would cause local flows to substantially exceed historical flows or cause channel velocities to exceed the scouring velocity threshold of approximately 3 fps, or cause local stages to be substantially reduced from historical stages.

- **Hydrodynamic effects on net channel flows.** A project alternative is considered to have a significant impact on net channel flows if it would cause monthly average net channel flows to increase substantially above historical net channel flows during DW operations.

Simulated Delta Hydrodynamics for Historical Conditions and the No-Project Alternative

Possible impacts of the DW project alternatives are compared below with Delta hydrodynamic conditions under the No-Project Alternative. This section describes the simulation results for the No-Project Alternative as the reference point that represents Delta hydrodynamic conditions under the 1995 WQCP. The RMA Delta model was used to simulate possible hydrodynamic effects of each of the DW alternatives and the No-Project Alternative in local channels for representative channel flows with maximum DW diversion and discharge conditions. The DeltaSOS model results for the 70-year period of 1922-1991 were used to evaluate changes in net channel flows at selected key Delta locations.

Comparison of Inflows, Exports, and Outflows under Historical Conditions and the No-Project Alternative

Monthly average net Delta channel flows simulated with the RMA model using historical 1967-1991 inflows and exports are presented as a reference in Appendix B1, "Hydrodynamic Modeling Methods and Results for the Delta Wetlands Project". Results from the RMA model simulations of net channel flows were incorporated into DeltaSOS for estimating net channel flows for historical and No-Project Alternative conditions.

The comparison of the No-Project Alternative with historical conditions provides a reference for understanding conditions under the No-Project Alternative. All impact assessments compare simulations of DW project operations with simulations of the No-Project Alternative.

Figure 3B-5 shows the comparison of the No-Project Alternative and historical 1967-1991 Delta conditions for Sacramento River and San Joaquin River inflows and Delta exports. Monthly average Delta inflows were about the same for historical conditions and the No-Project Alternative. Table B1-3 in Appendix B1 gives monthly historical inflows and exports for 1968-1991.

Simulated Delta exports for some years under the No-Project Alternative were substantially greater than historical exports, and Delta outflows were therefore correspondingly reduced in the No-Project Alternative simulations. Assumed minimum Delta outflows required to satisfy 1995 WQCP objectives under the No-Project Alternative are simulated to be slightly higher than historical conditions for some months of some years.

Figure 3B-6 shows simulated monthly Delta outflow, combined DCC and Georgiana Slough diversions, and central Delta outflow (QWEST flow) for the No-Project Alternative and historical conditions. Monthly average No-Project Alternative flows differ from historical flows because of differences in Sacramento River inflow, DCC closure standards, and Delta exports. Table B1-4 in Appendix B1 gives the monthly historical channel flows simulated with the RMA model for 1968-1991.

Simulated Delta Channel Flows for the No-Project Alternative

As described under "Criteria for Determining Impact Significance", three Delta channel locations have been selected for analysis of Delta hydrodynamic effects of DW project operations. DW project operations would most directly modify channel flows in the San Joaquin River downstream of the DW islands (e.g., San Joaquin River flow near Antioch), in Threemile Slough (flow from the Sacramento River to the San Joaquin River), and in Old and Middle Rivers between the DW islands and the Delta export pumps. Table B1-10 in Appendix B1 gives the monthly channel flows simulated by the DeltaSOS model (based on RMA model results) at selected Delta locations for the No-Project Alternative for water years 1968-1991.

The patterns of simulated flows for the No-Project Alternative were somewhat different from those of simulated historical flows in the San Joaquin River at Antioch, Threemile Slough, and Old River at Woodward Canal, as shown in Figure 3B-7. The No-Project Alternative simulation assumed 1995 WQCP Delta objectives and existing Delta facilities and water supply demands applied to the 1922-1991 hydrologic record, as documented in Appendix A2, "DeltaSOS: Delta Standards and Operations Simulation Model".

Simulated flows for the lower San Joaquin River at Antioch were generally lower under the No-Project Alternative than under simulated 1967-1991 historical conditions by several thousand cfs. Antioch flows were lower in the No-Project Alternative simulation primarily because No-Project Alternative export levels are higher than historical export levels, although some changes in Sacramento River inflows and diversions through the DCC, Georgiana Slough, and Threemile Slough also modify simulated net flows past Antioch. Reverse flows were simulated at Antioch for only a few months during 1967-1991 for both historical conditions and the No-Project Alternative.

Simulated flows in Old River (and Middle River) were larger in the upstream (negative) flow direction toward the Delta export pumps for the No-Project Alternative simulation than for historical conditions (Figure 3B-7). Simulated flows in Old River at Woodward Canal were about 50% higher than flows in Middle River at Victoria Canal. In contrast, USGS measurements suggest that the two channels should have nearly equal flows. Because this discrepancy in the relative flows in Old and Middle Rivers does not change the tidal flows or the total net flow moving toward the export pumps, there are no likely effects on the impact assessments caused by this discrepancy. Periods of downstream (positive) flows in Old and Middle Rivers, resulting from San Joaquin River inflows in excess of total Delta export volumes, were simulated only rarely for the No-Project Alternative.

Simulated Delta Inflow Source Contributions for the No-Project Alternative

Simulated contributions from each Delta inflow source to the Delta export locations (CCWD Rock Slough intake and the SWP Banks and CVP Tracy Pumping Plants) are governed by Delta hydrodynamics. Appendix B1, "Hydrodynamic Modeling Methods and Results for the Delta Wetlands Project", presents detailed RMA simulation results regarding inflow source contributions. These results have been summarized as representative export source contributions in the DeltaDWQ assessment model.

As simulated by the RMA model and approximated in the DeltaDWQ assessment model, most Delta export water comes from the Sacramento River in most months (see Table B1-12 in Appendix B1). In some months with substantial San Joaquin River inflows, the source contribution from the San Joaquin River to Delta exports was dominant. During the irrigation season, the simulated contribution from Delta agricultural drainage to Delta exports was variable at about 5%-10% for the No-Project Alternative. During winter periods, the contribution from agricultural island drainage was generally 20%-25% or higher.

IMPACTS AND MITIGATION MEASURES OF ALTERNATIVE 1

Under Alternative 1, water would be diverted for storage on Bacon Island and Webb Tract, and Bouldin Island and Holland Tract would be managed for wetlands and wildlife habitat under an HMP, possibly with limited conjunctive water storage. Under this alternative, the maximum storage volume of the two reservoir islands would be approximately 238 TAF. Maximum storage may increase slightly over the life of the project because of subsidence on the reservoir islands. Incidental storage on the habitat islands during certain seasons would be approximately 9 TAF.

Water would be diverted to the reservoir islands at a maximum monthly average diversion rate of 4,000 cfs, which would fill the two reservoir islands in one month. The maximum initial daily average diversion rate would be 9,000 cfs during several days when siphoning of water onto empty reservoir islands begins; at this time, the maximum head differential would exist between island bottoms and channel water surfaces. The maximum monthly average discharge rate is assumed to be 4,000 cfs, allowing the reservoir islands to empty in one month. The maximum initial daily average discharge rate would be 6,000 cfs.

Alternative 1 includes the assumption that DW discharge water is included in WQCP export pumping limits that depend on inflow. Under Alternative 1, discharges of water from the DW islands would be exported in any month when unused capacity within the permitted pumping rate exists at the SWP and CVP pumps and the 1995 WQCP export limits do not prevent use of that capacity. Such unused capacity could exist when the amount of available water (i.e., total inflow less Delta outflow requirements) is less than the amount specified by the export limits.

Figures 2-2 and 2-3 in Chapter 2, "Delta Wetlands Project Alternatives", show the proposed locations for siphon stations and discharge pump stations on the two reservoir islands. Localized hydraulic effects of siphons (with screens) and discharges will occur near these locations.

Hydrodynamic Effects of Maximum DW Diversions and Discharges on Local Channel Velocities and Stages

For hydrodynamic simulations of maximum DW siphoning operations to fill storage reservoirs, Delta inflows and exports were specified to produce flows and velocities in Delta channels expected during a typical period of high Delta inflows when DW would divert water to storage.

The DW diversion rate would be limited to a maximum of 9,000 cfs. This diversion rate would decrease as Bacon Island and Webb Tract were filled and the siphon head differential decreased, as described in the next section.

The DW discharge rate would be limited to a maximum of 6,000 cfs and this discharge rate would decrease as the reservoir islands were emptied and the pumping head increased.

Likely hydrodynamic effects in the channels surrounding the DW project were evaluated relative to the net flows and tidal flows in the channels surrounding the DW project islands. The results of these local hydrodynamic comparisons are detailed in Appendix B1.

DW Reservoir Island Siphon Hydraulics

Each DW reservoir island would have two siphon stations, each with 16 siphons having a diameter of 2.8 feet. Booster pumps would be included for some siphons as required to fill the reservoir islands to the maximum surface elevation of 6 feet above sea level. The siphon stations are more fully described in Chapter 2, " Delta Wetlands Project Alternatives".

Siphon hydraulics are governed by the head difference between the tidal stage and reservoir surface elevation; the fixed head loss through the fish protection screens; and the hydraulic head losses caused by friction and turbulence, which increase with velocity. The effective siphon head difference will generate a velocity "head" and a friction "head" that can be computed as follows:

$$\text{siphon head (ft) - head loss (ft)} = (1 + f \cdot L/D) \cdot V^2/(2 \cdot g)$$

where:

f = friction factor of about 0.015,

L = length (240 feet),

D = diameter (2.8 feet) of the siphon, and

g = gravitational force (32 ft/sec^2).

The constant head loss is expected to be less than 0.5 foot.

As the tide varies (from approximately 0 to +4 feet), siphon flow will vary as the square root of the total effective head. The siphon flow will decrease as the reservoir island fills. Booster pumps will be inserted into about half the siphons on each reservoir island to maintain a minimum filling rate of between 2,000 cfs down to 1,000 cfs as the effective head decreases. The booster pumps are assumed to provide a constant "boost" to the effective siphon head of approximately 8 feet.

The simulated diversion filling pattern for the siphons relative to fluctuating tidal stage is shown in Figure 3B-8 for either of the reservoir islands, with an initial diversion rate of 4,500 cfs for the 32 siphons. After about 2 weeks of siphoning (producing storage of 80 TAF), booster pumps that provide an effective head boost of 8 feet are simulated for 16 of the siphons, maintaining a diversion rate of greater than 1,000 cfs for the remainder of the filling period, which lasts a total of approximately 4 weeks.

DW Reservoir Island Discharge Hydraulics

Each DW reservoir island would have a single discharge station with 32 (Webb Tract) or 40 (Bacon Island) discharge pumps and pipes, as described and shown in Appendix 2 , "Supplemental Description of the Delta Wetlands Project Alternatives". As Figure 2-5 in Appendix 2 indicates, the discharge facilities would include submerged discharge expansion chambers located approximately 5 feet below low tide elevation so the discharge culverts would remain submerged throughout the tidal cycle.

Each discharge pump would have a maximum flow rate of about 100 cfs. The pipe would have a diameter of 3 feet and an inside area of about 6 square feet, so that the maximum pipe velocity would be about 16.5 ft/sec (100 cfs/6 ft2 = 16.5 ft/sec). The expansion chamber, with a width of 10 feet and a depth of 3 feet, would reduce the maximum discharge velocity to about 3.3 ft/sec (100 cfs/30 ft2). The maximum velocity of discharges entering the adjacent channel would therefore be slightly greater than the assumed scour velocity threshold of 3.0 ft/sec. However, the discharge would be horizontal and would flow into the channel above the bottom. The discharge leaving the expansion chamber can be described as a turbulent plane jet having certain well-known characteristics (Fischer et al. 1979).

A turbulent jet discharge will spread out as it enters the channel by entraining ambient water from the sides and bottom of the jet. The velocity will remain highest along the center of the jet and will be lowest at the edges of the jet. The proposed discharge pipes would be separated by 25 feet, so there would be about 15 feet of ambient water between the discharge expansion chambers (each chamber is 10 feet wide). Turbulent plane jets are observed to spread out at a constant angle of approximately 7°. The discharge jets will be expected to spread and join each other at a distance of about 65 feet. At this distance, the jet flow will be about 250 cfs and the average jet velocity will be approximately 2.1 ft/sec (maintaining the same momentum flux). At this distance, the discharge velocity will be less than the scour velocity threshold of 3 ft/sec and will be comparable to maximum tidal velocities of 1-2 ft/sec (see tidal velocity discussions in Appendix B1).

The discharge facilities would be clearly identified with pilings to anchor and protect the discharge culverts. The relatively high discharge velocities would be confined to the nearshore area (50-100 feet from shore) of the channels that are several hundred feet wide. The effects of the DW discharges therefore are not expected to have any localized significant impacts on channel scouring or on boating safety. The allowable mixing zone for purposes of water quality monitoring will be determined by SWRCB in cooperation with regional board requirements for similar jet discharges into tidal waters.

Hydrodynamics during Maximum DW Diversions and Discharges

Hydrodynamic changes caused by maximum DW project diversions would not persist throughout an entire diversion period of several weeks. After the first few days of diversions, hydrodynamic effects would decrease as siphoning rates decreased during filling in response to decreasing head differential.

The maximum DW diversions would occur at four siphon stations with capacities of 2,250 cfs each. Two stations are on Bacon Island, one on Middle River and one on Old River. The other two stations are on Webb Tract, one on the San Joaquin River and the other on False River, adjacent to Franks Tract. Proposed DW project filling would cause greatest hydrodynamic changes in Delta channels adjacent to the DW project islands in the central Delta. The results of RMA model simulations for diversions adjacent to each DW island are described in Appendix B1.

Table B1-7 in Appendix B1 lists the net flows in each major Delta channel simulated for the typical diversion period, with and without the maximum initial daily average DW diversions of 9,000 cfs. Figure B1-45 shows the directions of these net flows in the major Delta channels in the absence of DW diversions.

Hydrodynamics in the channels surrounding the project islands were simulated with maximum initial daily average DW discharges to estimate maximum expected changes during DW project discharge operations for all project alternatives.

Table B1-8 in Appendix B1 lists the net flows in each major Delta channel simulated for the typical discharge period, with and without the maximum DW discharges of 6,000 cfs. Figure B1-48 in Appendix B1 shows the direction of these net flows in the major Delta channels.

Hydrodynamic simulation of channel flows, velocities, and stages during periods of maximum DW diversion and maximum DW discharges indicate that the channel stages most affected by DW operations would be those in the south Delta. Table B1-9 in Appendix B1 lists simulated channel stages during periods of maximum DW diversions and discharges. The results indicate that stages would not be substantially changed by DW operations. The minimum and maximum stages would be lowered in some channels by as much as 0.25 foot (3 inches). However, because these south Delta channels normally experience tidal fluctuations of more than 5 feet, this is not considered a substantial change (5%) for these south Delta channels. These simulations did not include DWR's proposed south Delta project barriers. These tidal gates are designed to help control minimum tidal stages in south Delta channels and may also reduce the potential effects of DW operations on channel stages.

Summary of Project Impacts and Recommended Mitigation Measures

Impact B-1: Hydrodynamic Effects on Local Channel Velocities and Stages during Maximum DW Diversions. The hydrodynamic simulation results for the maximum possible initial daily average DW diversion rate of 9,000 cfs under Alternative 1 indicate that maximum possible channel velocities and stages are within the range of conditions normally encountered during tidal fluctuations in the Delta channels surrounding the DW project islands. No hydrodynamic effects resulting from maximum diversions were identified as significant. Therefore, this possible hydrodynamic impact is considered less than significant.

Mitigation. No mitigation is required.

Impact B-2: Hydrodynamic Effects on Local Channel Velocities and Stages during Maximum DW Discharges. The hydrodynamic simulation results for the maximum possible initial daily average DW discharge rate of 6,000 cfs under Alternative 1 indicate that maximum possible channel velocities and stages are within the range of conditions normally encountered during tidal fluctuations in the Delta channels surrounding the DW project islands. No hydrodynamic effects resulting from maximum discharges were identified as significant. Therefore, this possible hydrodynamic impact is considered less than significant.

Mitigation. No mitigation is required.

Hydrodynamic Effects on Net Channel Flows

DW monthly diversion and discharge operations were simulated with DeltaSOS as reported in Appendix A3, "DeltaSOS Simulations of the Delta Wetlands Project Alternatives". Under Alternative 1, the simulated 70-year average annual operations consisted of 222 TAF/yr of diversions and 188 TAF/yr of discharge for export.

Table A3-7 in Appendix A3 shows results of simulated monthly DW operations for the 70-year 1922-1991 simulation period. Operations are simulated as diversions to storage (cfs), end-of-month storage volume (TAF), and discharges for export (cfs). Model simulations show that diversions would generally occur early in a water year (October-February) and discharges of 2,000-4,000 cfs would generally occur during summer (June-August).

Table B1-11 (Appendix B1) shows simulated changes in channel flows for Alternative 1 compared with channel flows simulated for the No-Project Alternative at four selected Delta locations of concern for hydrodynamic effects for water years 1968-1991. This recent period includes a range of hydrologic conditions similar to those of the 1922-1991 period (Appendix A1). Outflow was reduced the DW diversion flow in the simulations. San Joaquin River flows at Antioch were simulated to be reduced by about 70% of the DW diversions during the months when water was being diverted to fill the reservoir islands. Threemile Slough flows from the Sacramento River were increased by about 30% of the DW diversion flow. Simulated flows in the Old and Middle River channels toward the export pumps would each be increased during months with DW discharges for export by approximately 50% of the DW discharges. The maximum net flows are not increased because these are controlled by the export capacity.

Summary of Project Impacts and Recommended Mitigation Measures

Impact B-3: Hydrodynamic Effects on Net Channel Flows. All simulated changes are well within the historical range of Delta channel flows at the locations selected for hydrodynamic impact assessment. The simulated flow changes would not result in significant hydrodynamic effects. Therefore, this possible hydrodynamic impact is considered less than significant.

Mitigation. No mitigation is required.

Effects on Inflow Source Contributions

Table B1-12 in Appendix B1 shows simulation results for inflow source contributions from the Sacramento and San Joaquin Rivers, Delta agricultural drainage, and the DW project islands to the representative Delta exports (CCWD Rock Slough intake and SWP Banks and CVP Tracy Pumping Plants) during 1968-1991 for the No-Project Alternative and the DW project alternatives. DW project discharges were simulated to contribute between about 15% and about 30% of the total amount of exported water. During months with substantial DW contributions, contributions from other inflow sources were reduced proportionately. No hydrodynamic impacts are associated with source contribution changes.

The potential water quality impacts resulting from these simulated DW discharge contributions at Delta export locations are evaluated in Chapter 3C, "Water Quality". The potential fishery effects of the increased pumping required to export DW discharges are evaluated in Chapter 3F.

IMPACTS AND MITIGATION MEASURES OF ALTERNATIVE 2

Alternative 2 would have the same physical arrangement and operating capacities as Alternative 1. The diversion-period modeling assumptions for this alternative are the same as for Alternative 1. Under Alternative 2, it is assumed that discharges from the DW islands would be exported by the SWP and CVP pumps when unused capacity within the permitted pumping rate exists at the SWP and CVP pumps. DW discharges would be allowed to be exported in any month when such capacity exists, without regard for the export limits (percentage of total Delta inflow). Under this alternative, it is assumed that export of DW discharges is limited by the WQCP Delta outflow requirements and the permitted combined pumping rate of the export pumps but is not subject to the 1995 WQCP "percent inflow" export limited.

The average monthly maximum diversion rate to storage on the reservoir islands under Alternative 2 would be 4,000 cfs; the maximum initial daily average diversion rate would be 9,000 cfs. The maximum monthly discharge rate is assumed to be 4,000 cfs, and the maximum discharge rate would be 6,000 cfs. Locations of siphon stations for project diversions and pumping stations for project discharges would be the same as those for Alternative 1, as shown in Chapter 2.

Under Alternative 2, DW discharge water would be allowed up to the permitted pumping capacity limits.

Hydrodynamic Effects of Maximum DW Diversions and Discharges on Local Channel Velocities and Stages

The analysis of effects of maximum diversions and discharges on local flow patterns for Alternative 2 would be identical to that described above for Alternative 1. The impacts of maximum DW diversions and discharges on local channel velocities and stages under Alternative 2 would be the same as under Alternative 1.

Hydrodynamic Effects on Net Channel Flows

Monthly operations for Alternative 2 were simulated with DeltaSOS as reported in Appendix A3, "DeltaSOS Simulations of the Delta Wetlands Project Alternatives". The 70-year average annual DW operations for Alternative 2 were simulated to be 225 TAF/yr of diversions and 202 TAF/yr of discharge for export.

Table A3-10 in Appendix A3 shows results of simulated monthly DW operations of Alternative 2 for 1922-1991. Diversions would generally occur during the early or middle part of a water year (October-March) and discharges would generally occur during the middle or late part of a year (February-March or June-August).

Detailed results of hydrodynamic simulation of Alternative 2 are presented in Appendix B1. Table B1-11 in Appendix B1 gives the simulated changes in channel flows for Alternative 2 compared with channel flows simulated for the No-Project Alternative. Outflow would be reduced by the DW diversion flow. San Joaquin River flows at Antioch would be reduced by an amount equal to 70% of the DW diversions during months when water was diverted to the DW reservoir islands. Threemile Slough flows from the Sacramento River would be increased by an amount equal to 30% of DW diversions. Simulated flows in the Old and Middle River channels would each be increased toward the export pumps by about 50% of the DW discharges during months with DW discharges for export. The changes in these channel flows correspond with the periods of DW diversions and discharges.

The impact of Alternative 2 on net channel flows would be the same as described for Alternative 1.

Effects on Inflow Source Contributions

Table B1-12 in Appendix B1 shows results for simulated source contributions from DW discharges at the representative Delta export locations for Alternative 2. The DW discharges were simulated to contribute between 15% and 30% of the total amount of exported water. The changes in other source contributions caused by DW discharges are also given in Table B1-11. No hydrodynamic impacts are associated with these changes. The potential water quality impacts resulting from these simulated DW discharge contributions at Delta export locations are evaluated in Chapter 3C, "Water Quality". The potential fishery effects of the increased pumping required to export DW discharges are evaluated in Chapter 3F.

IMPACTS AND MITIGATION MEASURES OF ALTERNATIVE 3

Under Alternative 3, water would be diverted for storage in reservoirs on all four DW project islands. A habitat reserve would be created on Bouldin Island north of State Route 12. Under this alternative, DW initial storage volume is assumed to be approximately 406 TAF; this volume may increase slightly over the life of the project.

The diversion-period modeling assumptions for this alternative are the same as for Alternatives 1 and 2. The discharge-period modeling assumptions for this alternative are the same as for Alternative 2 (permitted export pumping rate limits). Under Alternative 3, DW discharge water would be allowed up to the limits of the permitted export pumping rates.

The maximum average monthly diversion rate is assumed to be about 6,000 cfs, which would fill the four reservoir islands in about one month (maximum initial daily average diversion rate of 9,000 cfs). The maximum monthly average discharge rate is also assumed to be 6,000 cfs (maximum discharge rate of 12,000 cfs). Under Alternative 3, siphon and pump stations would be constructed on Bouldin Island and Holland Tract to support water storage operations on these islands (see Figures 2-10 and 2-11 in Chapter 2). Siphon and pump stations on Bacon Island and Webb Tract would be located as for Alternatives 1 and 2.

Likely DW monthly operations under Alternative 3 were simulated with DeltaSOS as reported in Appendix A3. The 70-year average annual DW operations for this alternative were simulated to be 356 TAF/yr of diversions and 302 TAF/yr of discharge for export.

Hydrodynamic Effects of Maximum DW Diversions and Discharges on Local Channel Velocities and Stages

The analysis of effects of maximum diversions and discharges on local flow patterns under Alternative 3 for Bacon Island and Webb Tract would be identical to that reported above for Alternative 1. Results of simulations of maximum diversions and discharges from Holland Tract and Bouldin Island under Alternative 3 were similar to results for Alternative 1. DW would divert water to Holland Tract from Old River and Franks Tract and would discharge from Holland Tract to Old River. DW would divert to Bouldin Island from Little Potato Slough and the Mokelumne River; and would discharge from Bouldin Island to Little Potato Slough.

Summary of Project Impacts and Recommended Mitigation Measures

Impact B-4: Hydrodynamic Effects on Local Velocities and Stages during Maximum DW Diversions. This impact is described above under Impact B-1. This impact is considered less than significant.

Mitigation. No mitigation is required.

Impact B-5: Hydrodynamic Effects on Local Velocities and Stages during Maximum DW Discharges. This impact is described above under Impact B-2. This impact is considered less than significant.

Mitigation. No mitigation is required.

Hydrodynamic Effects on Net Channel Flows

Table A3-13 in Appendix A3 shows the results of monthly simulated DW operations under Alternative 3 for 1922-1991. Model simulations show that diversions of 2,000-6,000 cfs would generally occur early in a water year (October-February) and discharges of 2,000-6,000 cfs would generally occur during the middle part (February-March) or late part (June-August) of a water year.

The DW project was simulated to have only limited operations in several years because of limited availability of water for diversions. The simulations showed the additional DW water storage capacity on four reservoir islands (406 TAF) used in most years when water was available, but water available for diversion limited the DW storage to less than the maximum capacity in some years.

Detailed results of hydrodynamic simulation of Alternative 3 are presented in Appendix B1. Table B1-11 in Appendix B1 shows monthly simulated changes in channel flows for Alternative 3 compared with channel flows simulated for the No-Project Alternative. Outflow would be reduced by an amount equivalent to the DW diversion flow. Simulated San Joaquin River flows at Antioch were reduced by 70% of DW diversions during months when water was diverted to fill the four reservoir islands. Simulated flows in Old and Middle River channels south of Bacon Island toward the export locations were each increased by about 50% of DW discharges during months with DW discharges for export. The changes in these channel flows correspond with the periods of DW diversions and discharges.

Summary of Project Impacts and Recommended Mitigation Measures

Impact B-6: Hydrodynamic Effects on Net Channel Flows. This impact is described above under Impact B-3. The simulated changes between the No-Project Alternative and Alternative 3 are considered less-than-significant effects because they are well within the historical range of Delta channel flows at these locations.

Mitigation. No mitigation is required.

Effects on Inflow Source Contributions

Table B1-12 in Appendix B1 shows the monthly simulated source contributions from DW discharges in the representative Delta exports for Alternative 3. Because of higher discharge capacity, DW discharges were simulated to contribute between 15% and 40% of the total exported water. The changes in other source contributions caused by DW discharges are also given in Table B1-12. No hydrodynamic impacts are associated with these changes. The potential water quality impacts from these simulated DW discharge contributions at Delta export locations are evaluated in Chapter 3C, "Water Quality".

IMPACTS AND MITIGATION MEASURES OF THE NO-PROJECT ALTERNATIVE

The No-Project Alternative (intensified agricultural use of the four DW project islands) represents Delta water supply conditions predicted under the 1995 WQCP objectives. Consumptive use of water to supply crop ET would likely be somewhat greater under No-Project Alternative intensified agriculture conditions compared with existing agricultural land uses, but not measurably so at the scale of monthly Delta water supply modeling (e.g., DWRSIM or DeltaSOS).

The DeltaSOS simulation results for the No-Project Alternative under the 1995 WQCP were described above under "Impact Assessment Methodology". The No-Project Alternative as simulated by DeltaSOS would not cause adverse hydrodynamic effects relative to existing conditions as of 1989.

CUMULATIVE IMPACTS

Cumulative hydrodynamic impacts were assessed qualitatively without specific simulations using the RMA Delta hydrodynamic model. As described in Chapter 3A, the cumulative water supply impacts of the proposed DW project were evaluated with the same set of WQCP Delta standards, but assuming SWP pumping permitted at full capacity at Banks Pumping Plant (10,300 cfs).

Cumulative impacts are the result of the incremental impacts of the proposed action when added to other past, present, and reasonably foreseeable future actions. DW project effects on hydrodynamic conditions are inextricably tied to past and present hydraulic modifications that have been made in the Delta for various beneficial purposes, such as levee construction for land reclamation and flood control; channel dredging for navigation and levee maintenance; channel enlargement and deepening for navigation; operation of diversion pumps, siphons, and drainage pumps; and construction of export pumping plants (CVP Tracy Pumping Plant, SWP Clifton Court and Banks Pumping Plant) and associated facilities for water management (i.e., the DCC and the Suisun Marsh salinity control gate).

The cumulative effects of the DW alternatives therefore were evaluated in conjunction with past and present actions in the previous sections, which assumed the existing arrangement of Delta channels and continued operation of existing Delta hydraulic facilities and diversions. The focus of this section is on the evaluation of impacts of the DW project alternatives added to impacts of other future projects. This cumulative impact evaluation is based on the following scenario: increased upstream demands; increased demands south of the Delta; an increased permitted pumping rate at the SWP Banks Pumping Plant (see Chapter 3A, "Water Supply and Water Project Operations"); implementation of DWR's South Delta and North Delta Programs; additional storage south of the Delta in Kern Water Bank, Los Banos Grandes Reservoir, Metropolitan Water District of Southern California's (MWD's) Domenigoni Reservoir and Arvin-Edison projects, and CCWD's Los Vaqueros Reservoir.

Future activities in the Delta will include continued maintenance of existing channels (dredging) and levees (placement of riprap and other reinforcement measures). New facilities (e.g., channel gates and barriers) may be constructed, and existing channels may be modified for navigation or for increased water conveyance (e.g., DWR North and South Delta Programs). Some existing agricultural lands may be converted to urban development or to wetlands and other wildlife habitat uses, changing the water diversion and discharge patterns for these lands.

Cumulative Impacts, Including Impacts of Alternative 1

The DeltaSOS simulations of the Alternative 1 under cumulative future conditions are summarized in the cumulative impact section of Chapter 3A and are described in Appendix A3, "DeltaSOS Simulations of the Delta Wetlands Project Alternatives". Alternative 1 would be operated in fewer years under cumulative conditions than under existing conditions because of limited availability of water for DW diversions. Because of greater assumed export pumping capacity, however, greater DW diversions for export were simulated in several of the years.

Impact B-7: Cumulative Hydrodynamic Effects on Local Channel Velocities and Stages during Maximum DW Diversions. Because the basic tidal hydraulics that control local channel velocities and stages are not expected to change substantially under cumulative future conditions, possible hydrodynamic impacts of Alternative 1 during maximum DW diversions under cumulative future conditions are expected to be similar to those described above for Impact B-1. This cumulative impact is considered less than significant.

Mitigation. No mitigation is required.

Impact B-8: Cumulative Hydrodynamic Effects on Local Channel Velocities and Stages during Maximum DW Discharges. Because the basic tidal hydraulics that control local channel velocities and stages are not expected to change substantially under cumulative future conditions, possible hydrodynamic impacts of Alternative 1 during maximum DW discharges under cumulative future conditions are expected to be similar to those described above for Impact B-2. This cumulative impact is considered less than significant.

Mitigation. No mitigation is required.

Impact B-9: Cumulative Hydrodynamic Effects on Net Channel Flows. Under future conditions, the full physical capacity (10,300 cfs) at SWP Banks Pumping Plant was assumed in the DeltaSOS simulations (see Appendix A3). Use of full capacity at the Banks Pumping Plant may require implementation of DWR's South Delta Project to provide sufficient channel conveyance and Clifton Court diversion capacity, to protect agricultural diversion siphons and pumps at low tidal stages, and to maintain water quality that is sufficient for south Delta irrigation uses. This may allow flows in the Old River and Middle River channels during periods of maximum Delta exports that are higher than historical flows . DW discharges would contribute to these channel flows during periods with available water for diversion and during periods with available export pumping capacity for DW discharges.

Pumping at full SWP capacity would increase, by about 3,620 cfs (6,680 cfs to 10,300 cfs), the total export capacity of the SWP pumps. Because the Old River and Middle River channels each carry about half of the export flow (not supplied by diversion from the San Joaquin River at the head of Old River), the increased assumed pumping rate under cumulative conditions would be expected to increase the maximum net flow in the Old and Middle River channels by about 1,800 cfs each. However, because tidal flows in these channels are substantial under No-Project Alternative conditions (see Appendix B1, "Hydrodynamic Modeling Methods and Results for the Delta Wetlands Project"), these channels (with modifications included in the DWR South Delta Project) are expected to provide sufficient flow conveyance for maximum export pumping without any hydrodynamic impacts from channel scouring or other hydraulic effects (i.e., navigation or recreation effects).

Nevertheless, because the possible hydrodynamic effects of DW project operations on south Delta channels under cumulative future conditions is uncertain at this time, this cumulative hydrodynamic impact is considered significant. Implementing Mitigation Measure B-1 would reduce Impact B-9 to less-than-significant level.

Mitigation Measure B-1: Operate the DW Project to Prevent Unacceptable Hydrodynamic Effects in the Middle River and Old River Channels during Flows That Are Higher Than Historical Flows. USGS and DWR tidal flow measurements (i.e., velocities and stages) in south Delta channels, as well as tidal hydrodynamic model simulations, should be used to determine the effects of DW operations and DW operations should be controlled to prevent unacceptable hydrodynamic conditions in south Delta channels. SWRCB water right terms and conditions and Corps permits should include appropriate measures to prevent adverse hydrodynamic effects caused by DW diversions and discharges. Measures that may be used to prevent unacceptable hydrodynamic effects include establishing minimum tidal stages and maximum channel velocities. DW operations would be reduced or eliminated during these extreme tidal conditions.

Cumulative Impacts, Including Impacts of Alternative 2

Cumulative hydrodynamic conditions in the south Delta for Alternative 2 will be the same as described for Alternative 1. The DeltaSOS simulations of operations of Alternative 2 under cumulative future conditions are summarized in the cumulative impact section of Chapter 3A and are described in Appendix A3. Alternative 2 would be operated in fewer years under cumulative conditions than under existing conditions because of limited availability of water for DW diversions. Because of greater assumed export pumping capacity, however, greater DW exports were simulated in several of the years. The cumulative impacts and mitigation measure are the same as described for Alternative 1.

Cumulative Impacts, Including Impacts of Alternative 3

Cumulative hydrodynamic conditions in the south Delta for Alternative 3 will be the same as described for Alternative 1. The DeltaSOS simulations of operations of Alternative 3 under cumulative future conditions are summarized in the cumulative impact section of Chapter 3A and are described in Appendix A3. Alternative 3 would be operated in fewer years, or with reduced diversions, under cumulative conditions in comparison with existing conditions because of limited availability of water for DW diversions. Because of greater assumed export pumping capacity, however, greater DW exports were simulated in several of the years. The cumulative impacts and mitigation measure are the same as described for Alternative 1.

Cumulative Impacts, Including Impacts of the No-Project Alternative

The No-Project Alternative, as simulated by DeltaSOS under cumulative conditions, would not cause adverse Delta hydrodynamic effects.

CITATIONS

Printed References

Arthur, J. F., and M. D. Ball. 1980. The significance of the entrapment zone location to the phytoplankton standing crop in the San Francisco Bay-Delta estuary. U.S. Department of the Interior, Water and Power Resources Service. Sacramento, CA.

California. Department of Water Resources. 1993. Sacramento-San Joaquin Delta atlas. Sacramento, CA.

DeHaven, R. W., and D. C. Weinrich. 1988. Inventory of heavily shaded riverine aquatic cover for the lower Sacramento River and the Sacramento-San Joaquin Delta, Parts I and II. U.S. Fish and Wildlife Service, Division of Ecological Services. Sacramento, CA.

Fischer, H. B., E. J. List, R. C. Y. Koh, J. Imberger, and N. H. Brooks. 1979. Mixing in inland and coastal waters. Chapter 9, "Turbulent Jets and Plumes". Academic Press. Orlando, FL.

Kelley, D. W. 1966. Description of the Sacramento-San Joaquin estuary. Pages 8-17 in D. W. Kelley (ed.), Ecological studies of the Sacramento-San Joaquin estuary. Part I. Zooplankton, zoobenthos, and fishes of San Pablo and Suisun Bays, zooplankton and zoobenthos of the Delta. (Fish Bulletin 133.) California Department of Fish and Game. Sacramento, CA.

San Francisco Estuary Project. 1993. Managing freshwater discharge to the San Francisco Bay/ Sacramento-San Joaquin Delta estuary: the scientific basis for an estuarine standard - conclusions and recommendations of members of the scientific, policy, and management communities of the Bay/ Delta estuary. San Francisco, CA.

Smith, L. H. 1987. A review of circulation and mixing studies of San Francisco Bay, California. (Circular 1015.) U.S. Geological Survey. Denver, CO.

Smith, D. J., and T. J. Durbin. 1989. Mathematical model evaluation of the proposed Delta Wetlands project on the hydrodynamic and water quality response of Suisun Bay and the Sacramento-San Joaquin River Delta system. (RMA 8808.) Resource Management Associates, Inc. Lafayette, CA.

Personal Communications

Leib, David I. Water resources specialist. Contra Costa Water District, Concord, CA. February 11, 1992 - letter containing computerized data files.

Suits, Bob. Delta Planning. California Department of Water Resources, Sacramento, CA. June 21, 1994 - telephone conversation.

Table 3B-1. Available Information for Describing Historical Delta Conditions

1. DAYFLOW, DWR's database for historical daily Delta flows

	Item	Source
A.	Sacramento River	USGS measurements
B.	San Joaquin River	USGS measurements
C.	Eastside streams (Mokelumne, Calaveras, Cosumnes Rivers)	USGS measurements
D.	Yolo Bypass	DWR estimates
E.	Delta exports	CVP, SWP, CCWD records
F.	Channel depletion	DWR estimates
G.	Delta outflow	DWR estimates
H.	DCC and Georgiana Slough	DWR estimates
I.	QWEST	DWR estimates

2. RMA-simulated monthly average net channel flows, based on monthly average DAYFLOW inflows, exports, and channel depletions

   A. Old River diversions
   B. Sutter Slough and Steamboat Slough diversions
   C. DCC and Georgiana Slough flow (monthly DCC operations)
   D. Threemile Slough flow
   E. Jersey Point flow
   F. Antioch flow
   G. Chipps Island flow
   H. Old River and Middle River flow (at Bacon Island)

Table 3B-2. Preliminary Model Calibration and Confirmation Tasks for Assessment of Impacts of the DW Project on Delta Hydrodynamics

Data	Model	Analysis	Results
Tidal stage for July 1979 at 12 Delta locations	RMA Delta hydrodynamic model	Tidal stage calibration of hydraulic roughness coefficients	Smith and Durbin (1989); Appendix B1
Average tide at Benicia	RMA Delta hydrodynamic model	Simulation of typical Delta tidal hydraulics (stages, flows, and velocities)	Chapter 3B; Appendix B1
Historical Delta inflows and exports for 1972, 1976, and 1978	RMA Delta hydrodynamic model and RMA Delta water quality model	Calibration with daily EC measurements at 19 Delta locations	Smith and Durbin (1989)
Historical monthly average Delta inflows and exports for 1967-1991 (from DAYFLOW)	RMA Delta hydrodynamic model	■ Simulated historical Delta channel flows	Appendix B1; Chapter 3B
		■ Estimated channel flow split relationships for the DeltaSOS model	Appendix B1; Appendix A3; Chapter 3B
Historical monthly average Delta flows and EC data at 12 locations (Reclamation and DWR)	RMA Delta hydrodynamic model and RMA Delta water quality model (EC data used to confirm hydrodynamic results)	■ Confirmation of simulated monthly historical EC patterns	Appendix B2; Chapter 3C
		■ Estimated channel EC relationships with Delta outflow and exports for the DeltaDWQ model	Appendix B2; Chapter 3C

Table 3B-3. Modeling Tasks for Assessment of Impacts of the DW Project on Delta Hydrodynamics

Data	Model	Analysis	Results
1922-1991 DWRSIM estimates of Delta inflows and exports	DeltaSOS	Delta inflows and exports for the No-Project Alternative, cumulative No-Project Alternative, and DW alternatives	Chapter 3A; Appendices A1 and A3
Representative Delta inflows and exports for maximum DW diversions and maximum DW discharges	RMA Delta hydrodynamic model	Simulated Delta channel tidal flows and velocities	Chapter 3B; Appendix B1
Simulated Delta inflows and exports for the No-Project Alternative and DW operations for each DW alternative	DeltaSOS	Simulated monthly Delta net channel flows	Chapter 3B; Appendix B1

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Table 3B-4. Impact Variables Selected for Assessment of Effects of DW Project Operations on Delta Hydrodynamics

Response Variable	Method of Analysis and Assessment	Locations for Assessment	EIR/EIS Chapter
Local channel velocities and stages	RMA model for maximum diversion and discharge	Channels adjacent to DW islands	3B
Delta export	70-year simulation of export using DeltaSOS	CCWD Rock Slough SWP Banks Pumping Plant CVP Tracy Pumping Plant	3A
Delta outflow	70-year simulation of outflow using DeltaSOS	Chipps Island/Collinsville	3C and 3F
Delta channel flow	70-year simulations using DeltaSOS	San Joaquin River at Antioch Threemile Slough Old River at Woodward Canal	3B

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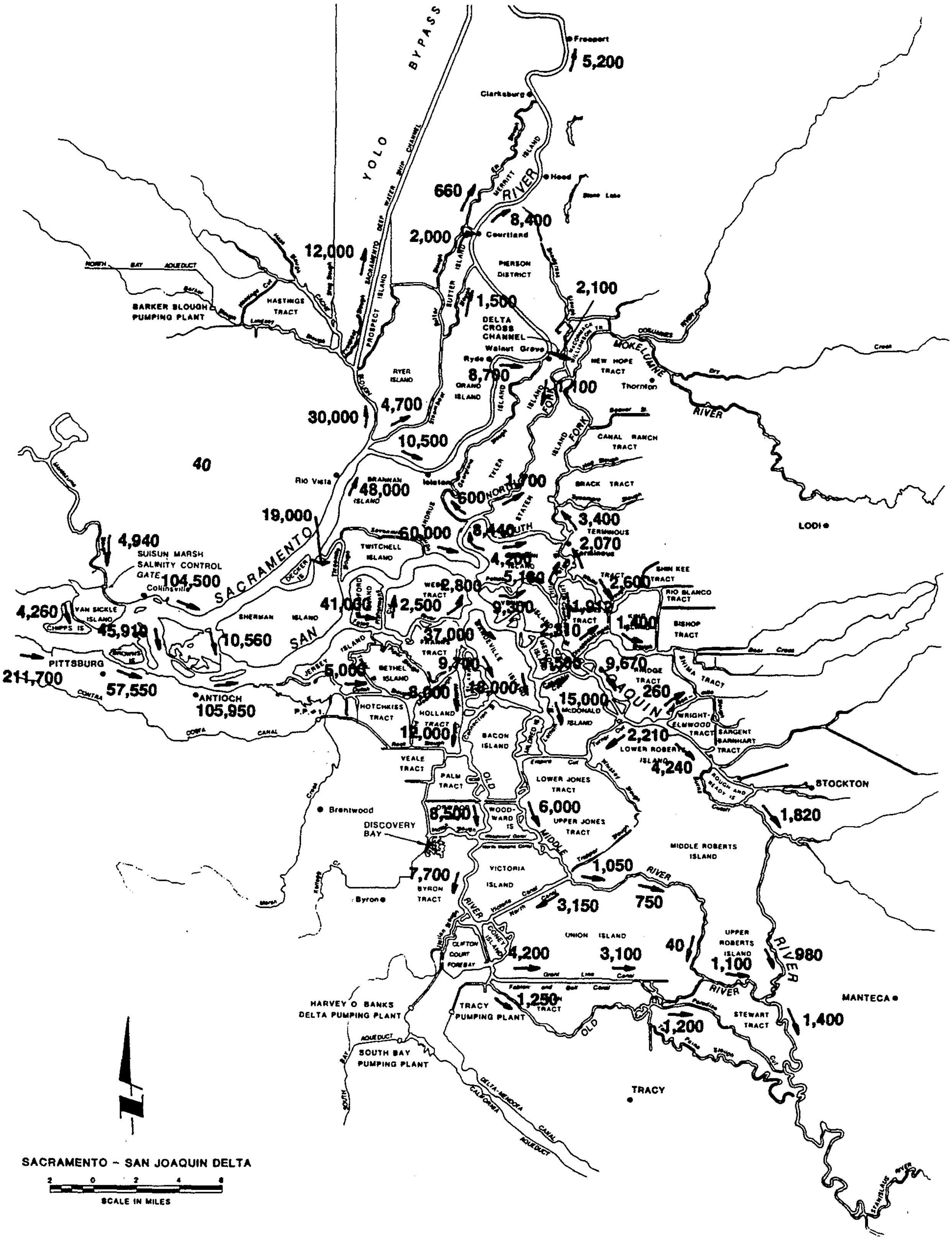


Source: Adapted from California Department of Water Resources 1993.

Figure 3B-1.
Average Flood Tide Flows (cfs) Simulated by the RMA Delta Model

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

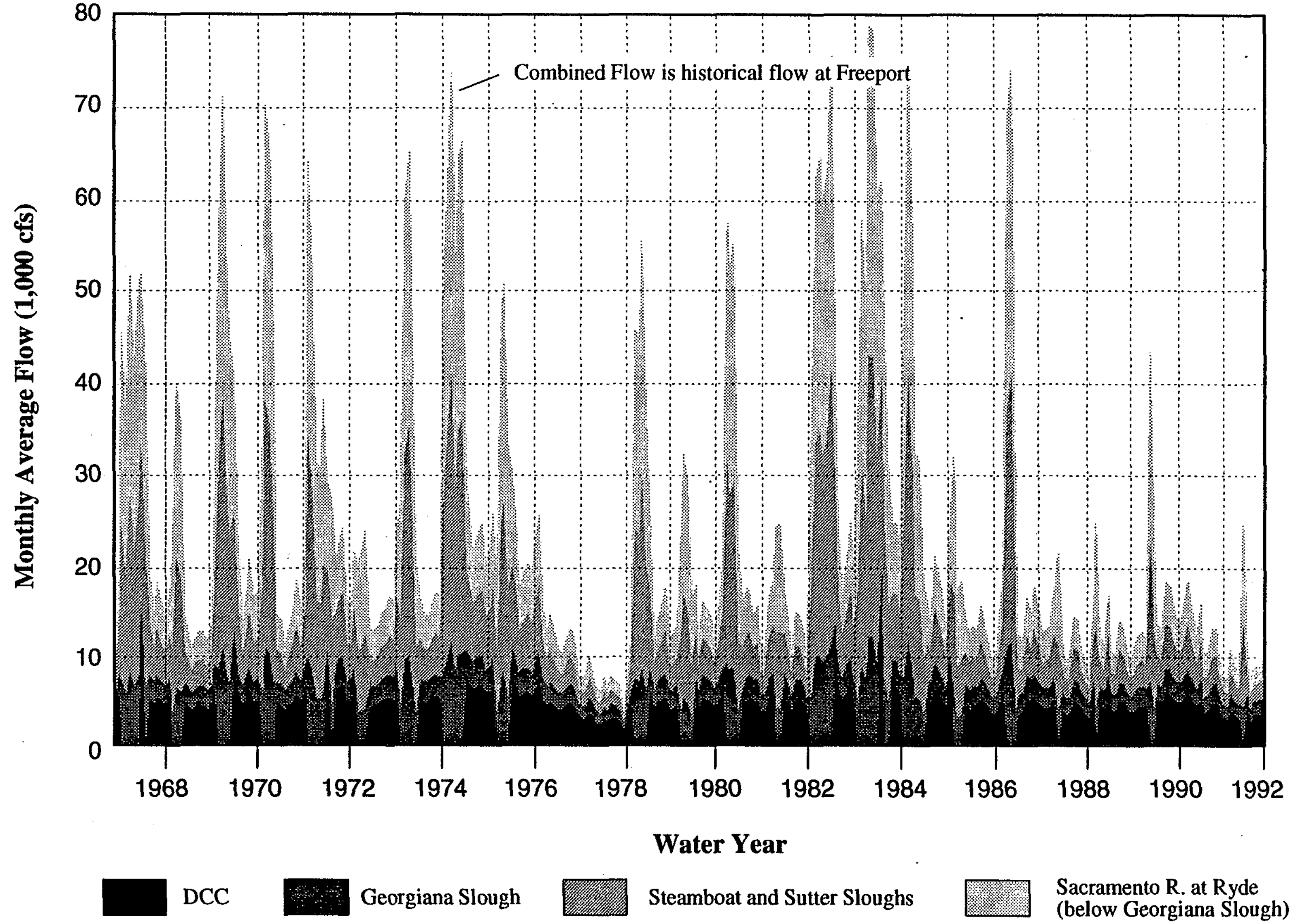


Figure 3B-2.
Monthly Average Historical Sacramento River Flow and Simulated Diversions to Steamboat and Sutter Sloughs, the DCC, and Georgiana Slough for 1967-1991

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

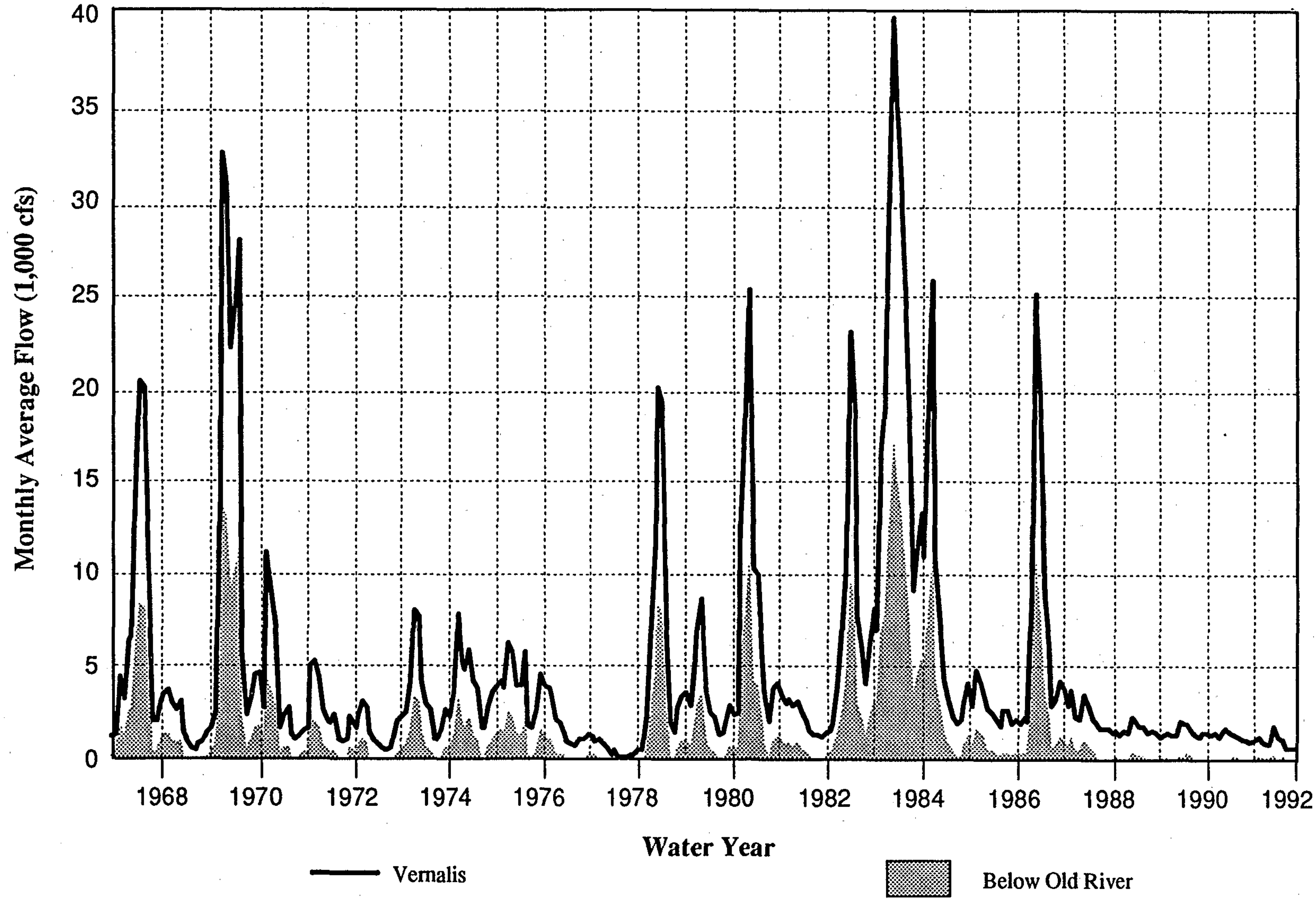
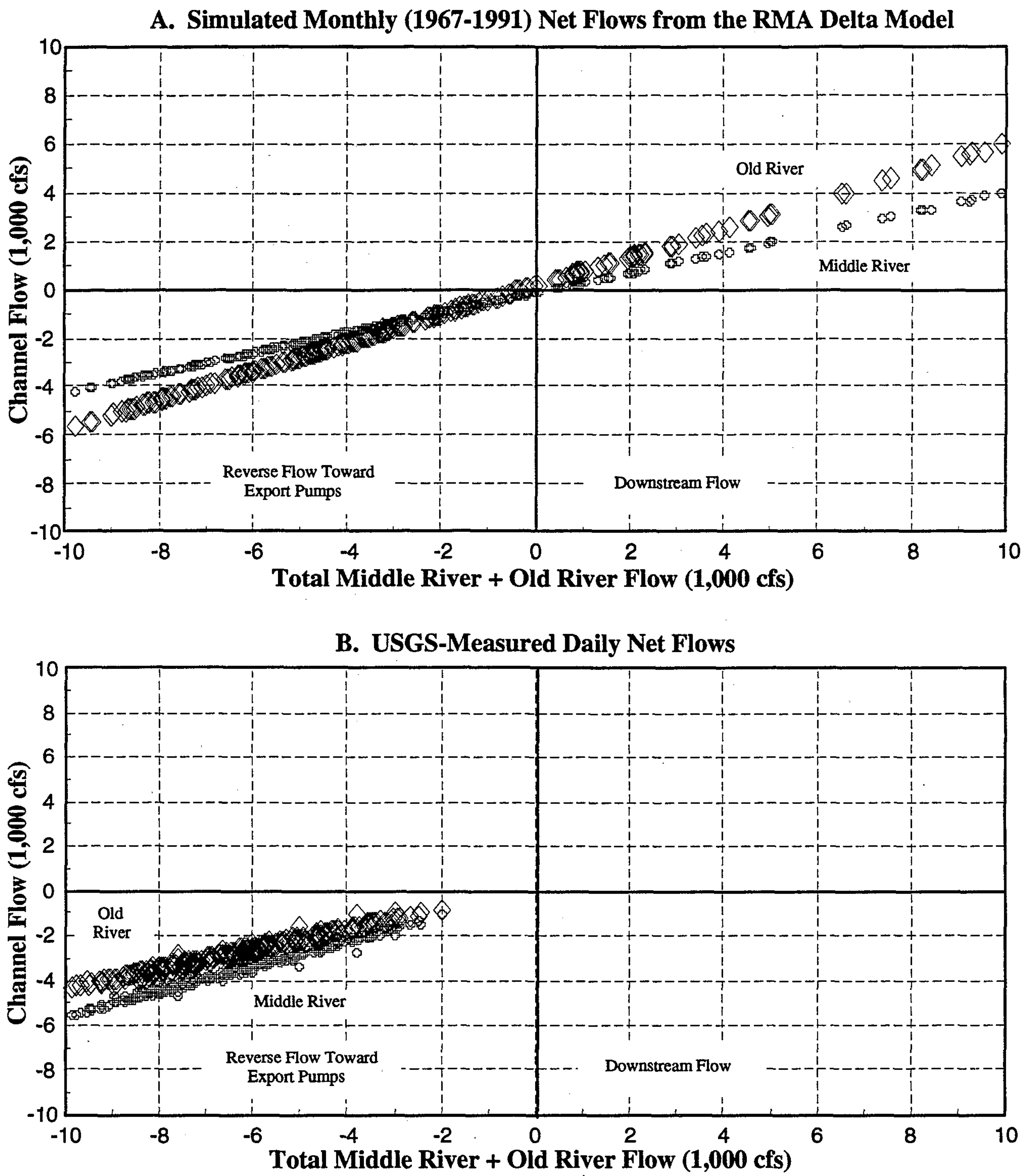


Figure 3B-3.
Monthly Average Historical San Joaquin River Flow at Vernalis and Simulated Flow Downstream of the Head of Old River for 1967-1991

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates



Source: 1990-1991 UVM data, USGS

Figure 3B-4.
Comparison of Simulated and Measured Old River and Middle River Channel Flows at Bacon Island Ultrasonic Velocity Meter (UVM) Stations

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

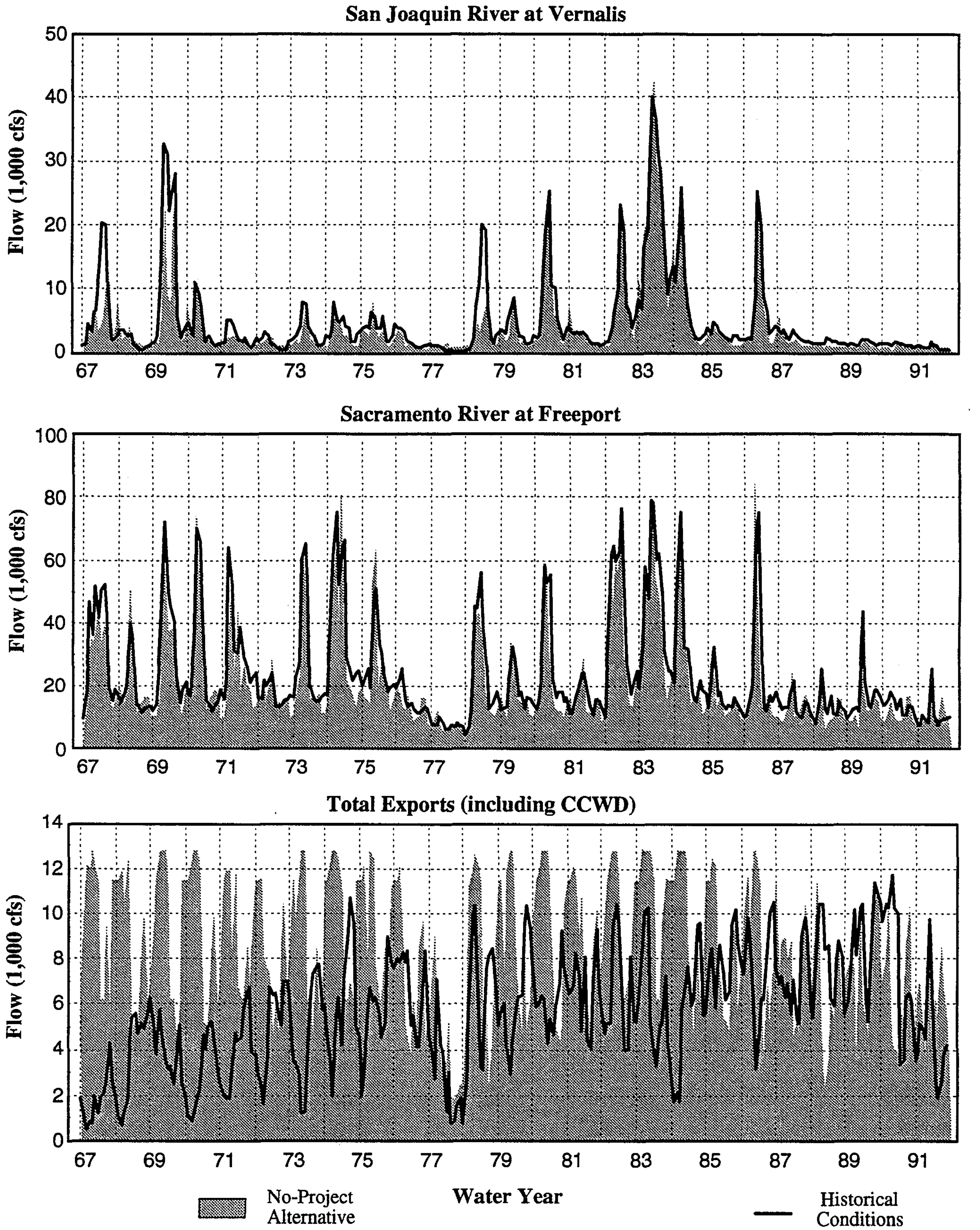


Figure 3B-5.
Simulated Monthly Average Delta Channel Flows for the No-Project Alternative and Measured Historical Conditions for 1967-1991

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

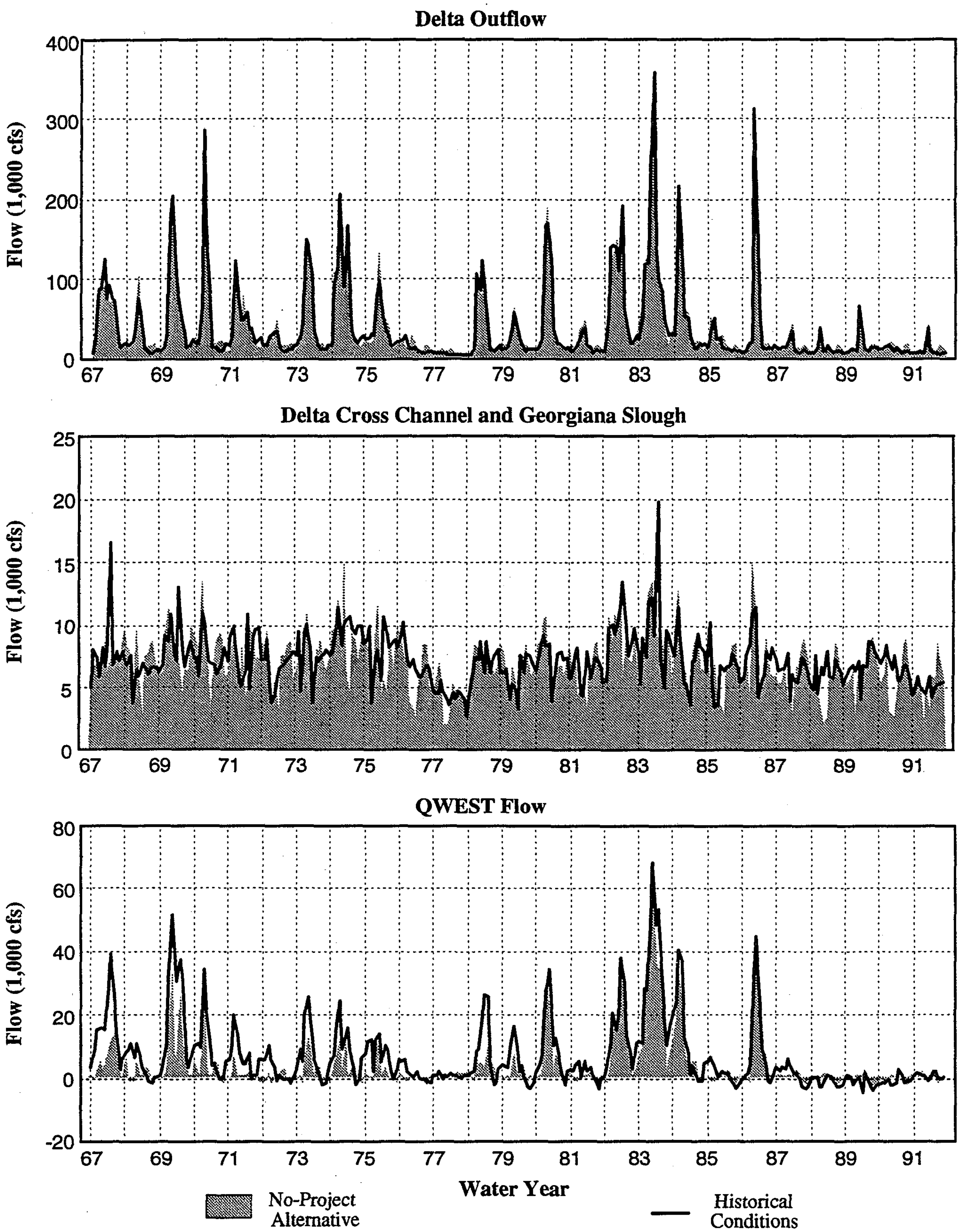


Figure 3B-6.
Simulated Monthly Average Delta Outflow, Channel Flows, and QWEST Flow for the No-Project Alternative and Simulated Historical Conditions for 1967-1991

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

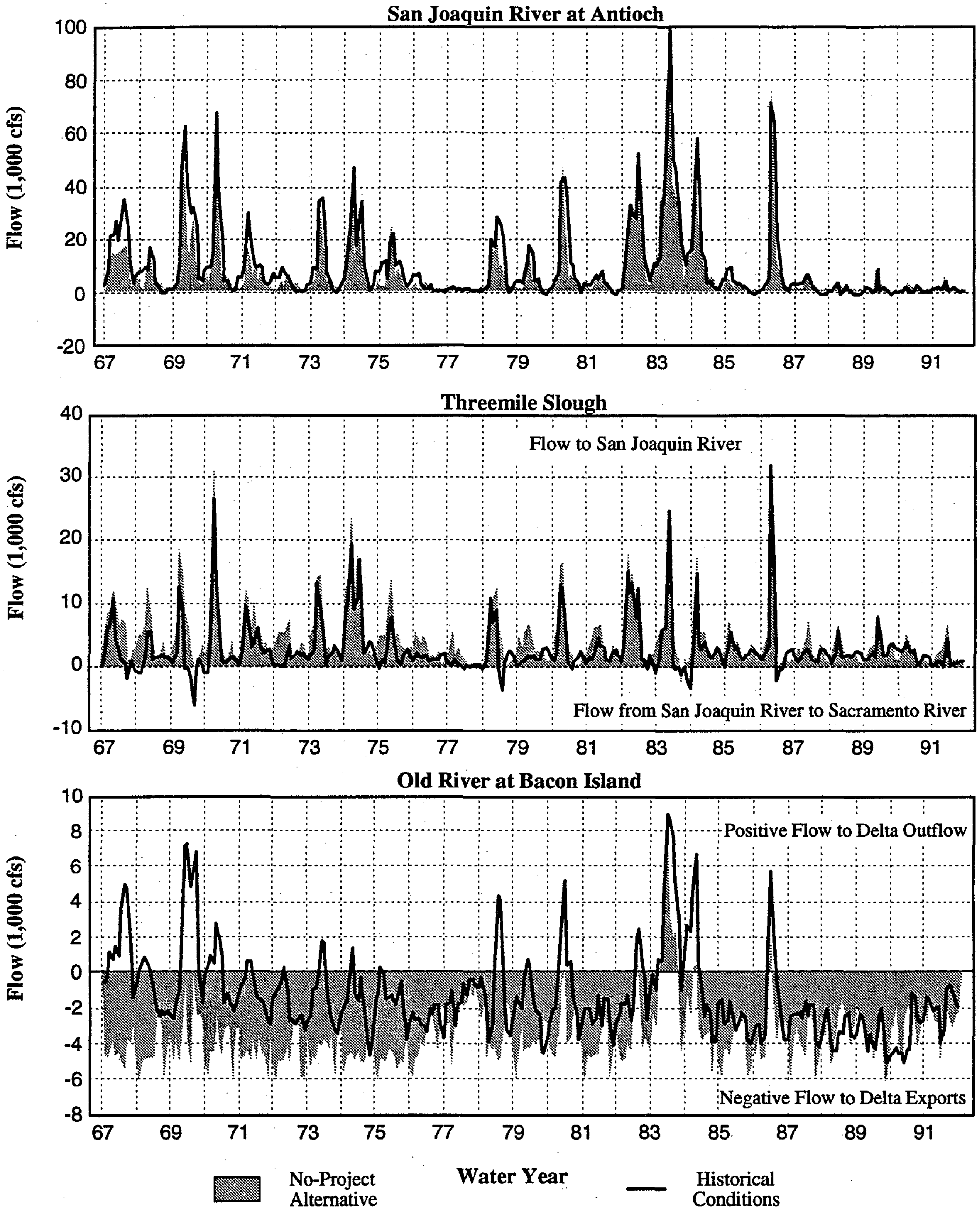


Figure 3B-7.
Simulated Monthly Average Flows in Selected Delta Channels for the No-Project Alternative and Simulated Historical Conditions for 1967-1991

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

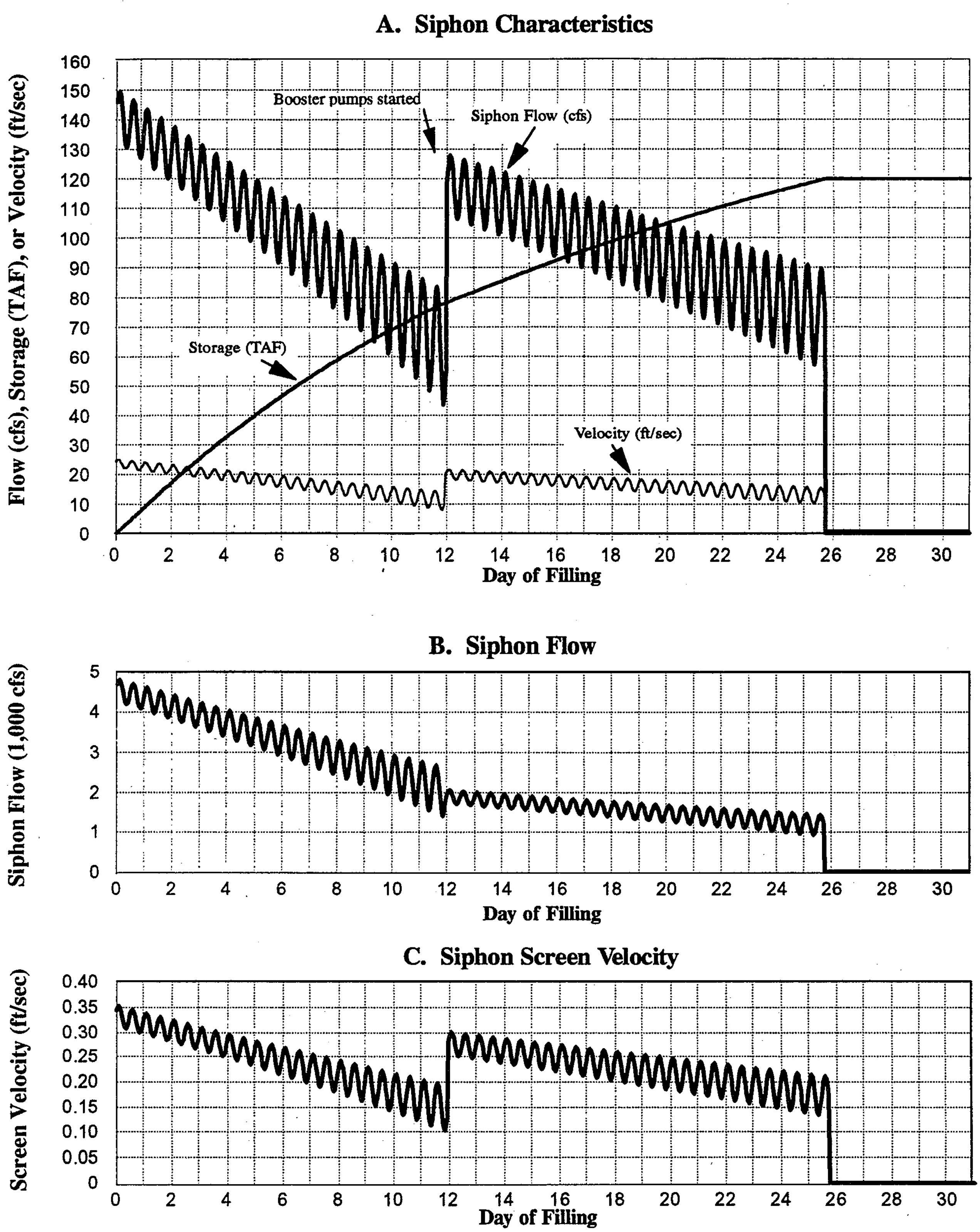


Figure 3B-8.
Simulated Flow Characteristics at a Typical DW Siphon Station during Reservoir Island Filling with Total of 16 36-inch Siphons and 16 36-inch Siphons with Booster Pumps

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

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